

An Analysis of Trade Credit and Macroeconomic Fluctuations



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This dissertation is submitted for the degree of
Doctor of Philosophy

Declaration

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Dissertation Summary

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Trade credit in the form of delayed input payments is an important source of financing for all types of firms. Empirical evidence on business cycle patterns and the usage of trade credit in the US economy suggests that trade credit comoves strongly with GDP and was severely affected at the onset of the 2008-2009 Financial Crisis. Motivated by these observations, this thesis studies the role of trade credit for the propagation of financial shocks in a production network and its implications for aggregate and sectoral outcomes.

To this end, I introduce a static quantitative multisector model featuring trade in intermediate inputs and endogenous trade credit linkages and costs between representative firms in each sector. Firms face working capital constraints and are required to finance their production costs using both bank and supplier credit. In response to a tightening of credit conditions, the endogenous adjustment in the volume and cost of trade credit captures two counteracting mechanisms: (1) Firms smooth interest rate shocks by substituting bank and supplier finance. (2) Any increase in the interest rate that a firm charges on trade credit tightens the financing terms of its customers thereby amplifying financial shocks. In equilibrium, the working capital constraint distorts the demand for production inputs and aggregate output as common to models with distortions. The interdependency of credit distortions further affects the propagation of financial shocks and it is shown that sectors extending a lot of trade credit to their customers relative to their own financing needs play a crucial role in the transmission of shocks to the cost of external funds.

In a quantitative application of the model to the US economy during the crisis, simulations featuring financial shocks only show that the model captures approximately a third of the drop in output, half of which can be attributed to the existence of trade credit linkages alone. I also show that the ability of firms to adjust their borrowing portfolio overall decreases aggregate volatility by less than two percent. This suggests that the smoothing mechanism of trade credit was operative, though small. In a final application, I quantify the predictions of the model and show that firms acting as important financial intermediaries for their customers are systemically important and generate large spillovers.

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Preface

The 2008-2009 Financial Crisis was characterized by a global collapse of credit markets that quickly transmitted to the corporate sector and led to a severe contraction of the aggregate economy. While the link between banks and firms has received considerable attention in the literature, the financial aspect of inter-firm trade as a propagation mechanism is a relatively new research agenda. Since trade credit in the form of delayed input payments is an important source of financing for all types of firms, this thesis studies the role of trade credit for the propagation of financial shocks in a production network and its implications for aggregate and sectoral outcomes.

After an introduction in Chapter 1, Chapter 2: *Trade Credit in the US Economy*, presents empirical evidence on business cycle patterns and the usage of trade credit in the US economy. I find that trade accounts payable of publicly traded, non-financial US firms account for approximately 11% of total corporate liabilities and its growth rate is pro-cyclical with, and more volatile than, the growth rate of real GDP. At the onset of the 2008-2009 Financial Crisis, the composition of short-term borrowing shifted towards bank credit, suggesting that liquidity in the market for trade credit was severely affected. In order to capture the heterogeneity of trade credit usage across firms, I propose a novel credit measure - the net-lending position of a firm - defined as the ratio of trade credit extended to customers and total production costs net of trade credit obtained from suppliers. The majority of US firms extend less trade credit than their upfront cost of production, while only a few act as financial intermediaries as measured by their net-lending position. I find a positive correlation between the decline in sectoral output during the crisis and a sector's overall dependency on supplier credit, suggesting that trade credit linkages affect the transmission of financial shocks and thus the real economy.

In Chapter 3, *A Multisector Model with Financial Frictions*, I propose a static quantitative multisector model with trade in intermediate inputs and endogenous trade credit linkages and costs between perfectly competitive intermediate good producing firms in each sector. Since firms face working capital constraints such that any sales are only realized after production has taken place, firms are required to finance production using both bank and supplier credit. In response to a tightening of credit conditions, the endogenous adjustment in the volume and cost of trade credit captures two counteracting mechanisms: (1) Firms smooth interest rate shocks by substituting bank and supplier finance. (2) Any increase in the interest rate that a firm charges on trade credit tightens the financing terms of its customers thereby amplifying financial shocks. In equilibrium, the working capital constraint distorts the demand for production inputs and aggregate output as common to models with distortions. The interdependency of credit distortions further affects the propagation of financial shocks and it is shown that sectors extending a lot of trade credit to their customers relative to their own financing needs play a crucial

role in the transmission of shocks to the cost of external funds.

Whether financial linkages amplify or dampen the effect of credit cost shocks on output is ambiguous and depends on the relative strength of the substitution and amplification effects outlined in Chapter 3 and thus remains a quantitative question. In the fourth and last chapter, *A Quantitative Assessment of Trade Credit and Aggregate Fluctuations*, the model economy introduced in Chapter 3 is first calibrated to the US at a sector level. I then simulate the model using shocks to a sector's cost of bank credit only, which are approximated using sector-level bond spreads obtained from the literature. The model reproduces - both qualitatively and quantitatively - business cycle patterns of trade credit as observed in the data and discussed in Chapter 2. It captures approximately a quarter of the variation of, and one third of the drop in, aggregate output during the financial crisis. Model simulations yield three main results with respect to the role of trade credit in propagating liquidity shocks during the 2008-2009 Great Recession: First, the existence of trade credit linkages can account for approximately 16% of the drop in aggregate output during the 2008-2009 crisis relative to an equivalent economy with bank-finance only. Second, the endogenous adjustment of the volume and cost of trade credit reduces aggregate volatility by 1.4%. Third, firms which extend a lot of trade credit in an economy and therefore act as important financial intermediaries for their customers are systemically important and generate large spillovers, which quantifies and confirms the model-prediction derived in Chapter 3.

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Chapter 1

Introduction

The flow of payments from customers to their suppliers plays a crucial role in maintaining the liquidity and turnover of products in a complex network of trade relations between firms. However, the time lag between the purchase of inputs and the receipt of payments for realized sales leads to a cash-flow mismatch for the producer and creates demand for ex-ante liquidity. In day-to-day operations, it is thus common practice for suppliers to offer payment terms in the form of trade credit, that allow customers to delay payments until after the delivery of the product. (see [Cuñat and García-Appendini, 2012](#))

Trade credit as a form of short- and medium-term debt "gives [firms] and [their] suppliers more flexibility to manage [their] businesses effectively through better cash flow management"¹ and represents an alternative source of financing to bank and financial market debt for all types of firms ([Petersen and Rajan, 1997](#)). However, at the onset of the financial crisis, the market for trade credit experienced a severe contraction, consequently forcing firms to use other sources of credit to fund their operations. (see [Costello, 2017](#); [Ivashina and Scharfstein, 2010](#)) Anecdotal and empirical evidence² highlights two countervailing features of trade credit: (1) Firms smooth interest rate shocks by substituting bank and supplier finance. (2) A tightening of supplier financing terms deteriorates the credit conditions for customers and has adverse and exacerbating effects on maintaining production.

In this thesis, I investigate the following two questions: Do trade credit linkages amplify or dampen the propagation of financial shocks? To what extent did the trade credit network contribute to the drop in output during the 2008-2009 Financial Crisis?

¹Kris Charles, Kellogg spokeswoman cited in [Strom \(2015\)](#), www.nytimes.com, 10/26/2018

²In 2008, there was considerable concern about the insolvency of GM and Chrysler and the resulting domino effect through the supply chain: "I don't think that suppliers will be able to get through the month without continued payments on their receivables" N.De Koker, CEO of the Original Equipment Suppliers Association. (see [Vlasic and Wayne, 2008](#), www.nytimes.com, 10/26/2018); As sales have been declining since 2011, SEARS - an American retailer - faced a considerable tightening of payment terms offered by their suppliers: "We cut their credit line and shortened payment terms [...] If they pay one day late, we will cut them off. [...] We want them to stay in business, [b]ut not at the risk to MGA." I.Larian, CEO of MGA Entertainment Inc. (see [Kapner, 2017](#), www.wsj.com, 10/26/2018)

For this purpose, I first build a quantitative multisector model where representative firms in each sector³ face working capital constraints and which explicitly accounts for both the substitutability of bank- and supplier credit and the input-output relations between sectors. In particular, I contribute to the literature by endogenizing the trade credit intensity between firms in order to capture the stabilizing and amplifying features outlined before. Subsequently, I apply the model to the US economy at a sector level and quantitatively assess the importance of the trade credit channel for the real economy. Furthermore, I derive a new credit measure - the net-lending position of a sector - which is defined as the ratio of accounts receivable⁴ to the difference between the total cost of production and accounts payable. It is shown that this novel measure helps to identify sectors which generate large spillovers through inter-firm credit linkages.⁵

This thesis makes three contributions to the literature: (1) I present stylised facts on business cycle patterns and the heterogeneity of trade credit usage in the US. (2) I then introduce a model which explicitly emphasizes the smoothing and amplifying features of trade credit and the implications of interdependent distortions for the propagation of shocks; and (3) I quantify the effect of trade credit linkages in the US economy on aggregate output.

Trade Credit in the US Economy. In the second chapter, I present stylised facts on business cycle patterns of aggregate trade credit in the US economy. Using yearly balance sheet data from Compustat of a panel of publicly-traded, non-financial firms from 1997 to 2016, I first calculate that trade accounts payable of non-financial US firms account for approximately 11.2% of total corporate debt and 5.0% of US GDP.⁶ It is then shown that the growth rate of the volume of trade finance is pro-cyclical with and more volatile than the growth rate of both current real GDP and total liabilities. In addition, the data also suggests that bank and trade credit are substitutes.⁷ Finally, I use the novel credit measure described above to show that, while there is heterogeneity across firms, the majority of US firms extend less trade credit than their own financing needs to cover their production costs net of trade credit obtained from suppliers. Only a few act as financial intermediaries by extending relatively more trade credit to customers. Furthermore, the direct and indirect exposure of sectors to their customers' and suppliers' trade credit

³With a slight abuse of language, I will use the term firm and sector interchangeably in the context of the model and the quantitative application presented in Chapter 3 and 4, respectively.

⁴Accounts payable(receivable) are the total outstanding payments owed to suppliers (by customers) for already delivered goods and services.

⁵Parts of this thesis have been published as a working paper version under the title "Finance-thy-Neighbor. Trade Credit Origins of Aggregate Fluctuations", available on www.margit-reischer.com

⁶The sample includes all Compustat firm-year observations from 1997 to 2016 of non-financial firms with their head-quarter in the US and positive and non-missing observations of the respective variables of interest. The sales of the firms included in the (reduced) sample represent approximately 34(19)% of total gross output in the US. For details on the sample selection and composition, see Appendix B.

⁷These patterns are in line with the findings in the literature. (see e.g. Cuñat, 2007, for an overview)

usage is positively correlated with the decline in output during the recent financial crisis, suggesting that trade credit linkages play an important role for the propagation of liquidity shocks. The model introduced in the third chapter of this thesis is evaluated based on its ability to reproduce, both qualitatively and quantitatively, these observed patterns.

A Multisector Model with Financial Frictions. In order to analyse the role trade credit plays in the propagation of financial shocks across firms, I then build a static quantitative multisector model with trade in intermediate inputs and endogenous credit linkages between perfectly competitive intermediate good producing firms in each sector. The banking sector is introduced in a reduced form by means of a sector-specific interest rate on bank credit, which contains a risk premium over the federal funds rate. The risk premium is subject to financial shocks and increases in the share of sales extended on trade credit to customers as suggested by the data. Since any sales are only realized after production has taken place, firms face working capital constraints and finance production using both bank and supplier credit.

At the beginning of a period, both productivity and financial shocks are realized. Profit-maximizing firms choose the composition of their borrowing portfolio to minimize their cost of production and optimally set the quantity produced and the average trade credit share extended to their customers, given demand, prices and interest rates. The endogenous adjustment of the volume and cost of trade credit or "trade credit channel" captures the two counteracting mechanisms presented earlier as follows: (1) On the demand side, firms respond to shocks to their bank risk premium by optimally trading-off credit costs on bank and trade credit and choosing the payment terms⁸ associated with the transaction. Hence, firms are able to smooth out any interest rate shocks by adjusting their borrowing portfolio which mitigates the negative effect of an increase in the bank interest rate on output. (2) On the supply side, a firm acts both as a supplier of goods and as a financial intermediary. Consider a firm which experiences an increase in its bank risk premium. Since the risk premium is increasing in the trade credit share extended to customers, a firm will optimally reduce the share of delayed sales. Consequently, the interest rate charged on trade credit increases, which directly affects the cost of credit and thus production of downstream customers. Similarly, a shift in the borrowing portfolio composition of a firm towards trade credit increases the cost of bank finance of upstream suppliers. This creates an amplification mechanism by which idiosyncratic shocks to the cost of bank credit are propagated both up- and downstream.

In equilibrium, it is shown that the working capital constraint introduces a credit wedge between the firm's marginal revenue and costs thereby distorting a firm's optimal

⁸The optimal payment schedule is defined as the cost-minimizing share of input expenditures financed via supplier credit. The effective price a customer pays is a bundle of the actual goods price and the cost of the financial service provided by its supplier.

input and output choice away from its optimal scale. At the aggregate level, the financial distortions manifest themselves in equilibrium as (1) an aggregate efficiency wedge decreasing Total Factor Productivity (TFP) and as (2) an aggregate labor wedge introducing a wedge between the household's marginal rate of substitution between consumption and labor and the economy's marginal rate of transformation as common to models with distortions. (see [Bigio and La'O, 2017](#); [Baqae and Farhi, 2018](#)) However, credit wedges in this thesis are a weighted average of both interest rates on bank and supplier credit and the weights are the optimally chosen link-specific trade credit shares. Therefore, this paper features endogenous and interdependent distortions affecting the propagation of financial shocks. It is shown that to a first order approximation, the net-lending position of a sector determines the relative importance of the smoothing and amplification mechanism of the trade credit channel.

Quantitative Application. Whether financial linkages amplify or dampen the effect of credit cost shocks on (aggregate) output is ambiguous and thus remains a quantitative question as the answer clearly depends on the relative strength of the substitution and amplification effects outlined before. To this end, I first calibrate the production structure and the inter-industry credit flows of the model-economy to the US at a sector level. I then simulate the model using only shocks to a sector's risk premium based on sector level bond spreads derived in [Gilchrist and Zakrajšek \(2012\)](#), GZ-spreads hereafter. Thereby, I exclude any additional source of variation affecting the economy such as productivity shocks. Simulations then show that the model reproduces - both qualitatively and quantitatively - business cycle patterns of trade credit as observed in the data. In particular, the model featuring the endogenous adjustment of the volume and cost of trade credit captures approximately a quarter of the variation in aggregate output while solely taking into account financial shocks. The model predicts that in response to an increase in sector-specific bank risk premia during the recent financial crisis, bank and supplier credit rates rose by approximately 45bps(20.1%) and 105bps(26.5%) on average. Since bank and trade credit are treated as substitutes, the model implies a drop in the share of inputs purchased on supplier credit by 3.4%, which accounts for 18.7% of the decline observed in the data presented in Chapter 2. Ultimately, the increase in the cost of bank finance translated into a 0.9% and a 0.6% decline in GDP and labor, respectively, accounting for approximately 34.3% and 10.0% of GDP and labor movements documented during the crisis. As the model predictions are based on financial shocks only, this highlights the quantitative importance of changes in financial frictions and their effect on aggregate output which corresponds to the findings in [Christiano et al. \(2015\)](#). I then quantify the role of trade credit for the propagation of liquidity shocks during the 2008-2009 Great Recession. The three main results are as follows:

In order to evaluate the aggregate effect of the trade credit network, I define the *trade credit multiplier* as the ratio between the percentage drop in the variable of interest generated by an economy with both trade and bank finance and an equivalent economy with bank finance only. The latter represents the benchmark economy discussed in [BL\(2017\)](#). The counterfactual exercise predicts a multiplier of around 1.9 for output, implying that the existence of the trade credit network per se almost doubled the decline in output during the crisis relative to an economy with bank finance only. In other words, the model suggests that approximately 16% of the drop in output during the financial crisis can be accounted for by trade credit linkages alone. Thus, the existence of an inter-firm credit network increases aggregate fluctuations following an aggregate financial shock.

The contribution of the *trade credit channel* - the endogenous adjustment of the volume and cost of trade credit - to changes in aggregate output is evaluated by comparing the general to the partial equilibrium response of the variables of interest. The latter is obtained when both trade credit interest rates and shares are kept at their steady state level. The difference can be attributed to the trade credit channel. Simulations suggest that the trade credit channel reduces aggregate volatility by 1.41% and dampened the drop in output during the financial crisis by 1.75%. Lastly, I quantify the main result of the theory section of this thesis and show that the trade credit multiplier implied by a financial shock to the top five sectors with the highest *net-lending ratio* is significantly higher than the trade credit multiplier generated by the same financial shock to the five sectors with the lowest net-lending ratio, as predicted by the model.

Related Literature. This thesis relates to four strands of literature: First, trade credit contracts have been studied more commonly in the *corporate and trade finance* literature: A growing theoretical literature - [Emery \(1984\)](#), [Smith \(1987\)](#), [Biais and Gollier \(1997\)](#), [Burkart and Ellingsen \(2004\)](#), [Cuñat \(2007\)](#) among others - investigates both the characteristics and motives of firms to engage in financial intermediation, rationalizing the existence of trade credit with the presence of transaction costs, imperfect market competition, information asymmetries or moral hazard problems. (see [Cuñat and García-Appendini, 2012](#)) The improvement in the availability of data has also spurred empirical contributions investigating and quantifying the empirical relevance of each motive for financial intermediation among firms. (i.a. [Petersen and Rajan, 1997](#); [Huang et al., 2011](#); [Giannetti et al., 2018](#)) In the context of international trade, financial frictions have been recognized as an important determinant of export decisions of firms ([Manova, 2013](#); [Chaney, 2016](#)). The recent 2008-2009 Financial Crisis has led to a growing literature investigating the optimal payment contract choice to finance international transactions ([Schmidt-Eisenlohr, 2013](#); [Antras and Foley, 2015](#)) as well as their implications for trade flows and the economy ([Chor and Manova, 2012](#)). Although related, this thesis focuses on the macroeconomic effects of credit markets on the domestic economy.

Second, starting with [Bernanke et al. \(1996\)](#), credit market frictions and their implications for the macroeconomy have received considerable attention in the literature. In these models, distortions in financial markets are at the origin of transmitting and amplifying financial shocks to the real economy by affecting the borrowing constraints of firms. Since the trade credit channel discussed in Chapter 3 also features a mechanism that amplifies the negative effect of financial shocks on output, it is related to the concept of the *financial accelerator* introduced in [Bernanke et al. \(1996\)](#). However, while the literature on the financial accelerator emphasizes the role of net-worth for collateral constraints and investment decisions, this thesis studies the direct interplay between bank- and trade credit in the context of a production chain where firms face working capital constraints, the relevance of which for the macroeconomy is still understudied.

Third, this thesis is related to an extensive literature investigating the *effects of micro-level distortions* on aggregates outcomes. This strand can be broadly classified into two substrands: The first sub-strand abstracts or limits the extent of inter-sectoral trade (see i.a. [Chari et al., 2007](#)), the second sub-strand explicitly accounts for (some degree of) intermediate goods trade (see i.a. [Jones, 2011](#)). More recent contributions by [Baqaee and Farhi \(2018, 2019\)](#) develop a more unified framework for the aggregation of micro-level distortions. Since my model builds on [Bigio and La'O \(2017\)](#), [BL\(2017\)](#) hereafter, it is clearly related to the second strand. While [BL\(2017\)](#) treat the distortions as exogenous, my contribution to this literature is the emphasis of the role of interdependent endogenous distortions for the propagation of shocks in the form of credit linkages among firms due to working capital constraints.

Fourth and foremost, this paper is related to the growing literature which studies *distortions in the context of a production network*. Since the seminal contribution of [Long and Plosser \(1983\)](#), a growing literature investigates the importance of production networks - the structure of intersectoral trade - for understanding how idiosyncratic shocks affect aggregate dynamics in an economy. (see [Carvalho, 2014](#); [Carvalho and Tahbaz-Salehi, 2018](#), for an overview)

Following the 2008-2009 recession, the interconnection of banking institutions and their role in the propagation of financial shocks have been studied extensively (see i.a. [Acemoglu et al., 2015](#)). The financial crisis also spurred empirical contributions on the real effects of credit shocks by focusing on the link between banks and firms (i.a. [Chodorow-Reich, 2014](#); [Iyer et al., 2014](#); [Cingano et al., 2016](#); [Alfaro et al., 2018](#)). However, the financial aspect of inter-firm trade as a transmission mechanism is a relatively new research agenda. While the effect of the interconnectedness of firms via customer-supplier relations on a firm's financial policy has recently received more attention in the corporate finance literature ([Kale and Shahrur, 2007](#); [Hertzel et al., 2008](#); [Banerjee et al., 2008](#); [Gao, 2014](#)), this thesis is related to the strand of literature focusing on the role of production

and financial linkages for the propagation of shocks to the real economy. Recent empirical contributions by [Raddatz \(2010\)](#) at a sector level and [Jacobson and von Schedvin \(2015\)](#), [Costello \(2017\)](#), [Cortes et al. \(2018\)](#), [Dewachter et al. \(2018\)](#) at a firm level confirm the relevance of trade credit linkages among production units for the propagation of liquidity shocks and thus real outcomes. Despite their quantitative importance, trade credit linkages have received little attention in the existing theoretical literature on business cycle fluctuations and comovements, with the exceptions most related to this thesis discussed below.

The relevance of trade credit for the propagation of liquidity shocks in a credit chain due to trade credit defaults has first been recognized in the important contribution by [Kiyotaki and Moore \(1997\)](#). However, the role of the network of trade credit relationships for the propagation of financial shocks and their aggregate implications in a business cycle model was first explicitly highlighted in [Altinoglu \(2018\)](#). Recent contributions by [Zhang \(2017\)](#), [Luo \(2018\)](#) and [Shao \(2017\)](#) investigate the implications of trade credit relations for sectoral comovement, the relative effect of financial shocks on up- and downstream sectoral outcomes and for aggregate fluctuations, respectively. This thesis contributes to the literature by quantifying (a) the role of trade credit as both a stabilizer and an amplifier of financial shocks and (b) the implications of credit linkages for the interdependency of credit distortions and subsequently for aggregate and sectoral outcomes. By emphasizing these counteracting features of trade credit, I relate to the mixed empirical evidence on the role of trade credit for firm level outcomes presented in, for example, [Garcia-Appendini and Montoriol-Garriga \(2013\)](#) and [Costello \(2017\)](#). The set-up of the model allows me to discuss mechanisms via which financial shocks propagate, and to decompose the response of output into effects attributed to each channel. Therefore, this thesis also relates to a sub-strand of the networks literature investigating the contagion and stabilization potential of linkages which have been discussed more extensively in the context of banking networks (i.a. [Allen and Gale, 2000](#); [Acemoglu et al., 2015](#)).

Since the main novelty of this thesis is the introduction of interdependent distortions via trade credit linkages in a multisector model, I now contrast the modelling approach in this thesis to that used in related work featuring endogenous trade credit choices:

First, in order to endogenize the credit link intensity between firms I follow [Luo \(2018\)](#) and let the share of input expenditures financed using trade credit be chosen by a profit-maximizing firm. This contrast the set-up in [Zhang \(2017\)](#), where all firms engage in Nash-bargaining and in [Shao \(2017\)](#), who introduces the level of trade credit as a choice variable. [Altinoglu \(2018\)](#) assumes the extend of credit links to be a fixed proportion of firms' sales. *Second*, unlike [Zhang \(2017\)](#), [Luo \(2018\)](#) and [Shao \(2017\)](#) where the extension of trade credit affects a firm's borrowing constraint, I explicitly impose the timing restriction that at the time a firm needs to finance its input expenditures, no sales have been realized.

Third, as opposed to [Zhang \(2017\)](#), firms choose the input-specific credit mix in order to minimize cost of production similar to [Luo \(2018\)](#), such that trade credit in this model is introduced by affecting the total cost of production via prices rather than collateral constraints. *Fourth*, by exploiting the positive empirical relationship observed in the data between sectoral credit spreads and the share of sales made on credit (see Chapter 2), I impose that the cost of short-term bank credit lines is increasing in the share of sales extended on trade credit. In particular, this assumption introduces a direct upstream cost-effect independent of any additional frictions in the banking sector, through which trade credit affects bank interest rates directly. In contrast, [Luo \(2018\)](#) generates both up- and downstream propagation patterns by explicitly modeling the financial sector following [Gertler and Karadi \(2011\)](#) such that bank credit costs are only indirectly affected by the credit portfolio choice of firms. *Fifth*, unlike [Luo \(2018\)](#) and [Zhang \(2017\)](#), I explicitly model the cost of trade credit extended to a firm's customers - similar to [Shao \(2017\)](#) - while firms take both input prices and the cost of supplier credit as given. *Lastly*, while [Shao \(2017\)](#) introduces trade credit into a dynamic general equilibrium two sector model with heterogeneous firms, the model proposed in this thesis features a more general and richer network structure with a representative firm in each sector instead. In particular, this allows to study the implications of firms simultaneously borrowing and lending from other firms for the transmission of financial shocks.

To summarize, I contribute to the literature on endogenous trade credit linkages in a production network by providing a tractable model that allows to study (a) the role of trade credit as both an stabilizing and a contagion device of financial shocks and (b) the relationship between bank and supplier finance over the business cycle by explicitly modelling the price of trade credit. To the best of my knowledge, this thesis is the first to explicitly emphasise and quantify non-linearities in the effect of interlinked distortions on aggregate outcomes while explicitly taking into account the direct interaction between bank and supplier credit via prices in a simplified framework.

Outline. The remainder of this thesis is organized as follows. Chapter 2 discusses empirical regularities of trade credit over the business cycle and of the heterogeneity of the net-lending position across sectors. Chapter 3 introduces the model: In Section 3.1 I characterize the equilibrium of this economy and Section 3.2 derives the main results with respect to the business cycle implications of trade credit linkages in an economy as suggested by the model. Chapter 4 presents a quantitative assessment of the role of trade credit in the US economy during the Great Recession.

Chapter 2

Trade Credit in the US Economy

The 2008-2009 Financial Crisis was characterized by a global collapse of credit markets that quickly transmitted to the corporate sector and led to a contraction of real (US) GDP in advanced economies by 3.4(2.6)%¹. An important role in the transmission of the liquidity shock from the banking to the real sector was played by trade credit relations among firms. (see e.g. [Jacobson and von Schedvin, 2015](#); [Costello, 2017](#)) In order to incorporate credit linkages into a multisector model, Section 2.1 first summarizes stylized facts on the relevance and cyclical properties of trade credit in the US economy at an aggregate and sectoral level, that will be informative for the set-up of the model in Chapter 3. Section 2.2 then elaborates on the effect of trade credit on output growth during the recent 2008-2009 recession.

For this purpose, I obtain yearly balance sheet data from Compustat of a panel of publicly-traded, non-financial firms² from 1997 to 2016, whose nominal sales represent approximately 34% of total gross output in the US. Although trade credit is more intensively used by small and medium-sized enterprises (SMEs) with a lower degree of access to both bank finance and financial markets (see i.a. [Petersen and Rajan, 1997](#)), supplier credit still represents a non-negligible source of financing for large publicly-traded firms. In particular, total accounts payable (receivable) account for approximately 11.2(9.5)% of total liabilities (assets) and make up approximately 5.0(6.5)% of US GDP³. Even though these magnitudes represent a lower bound for the usage of trade credit by US firms, they highlight the quantitative importance of supplier credit for the aggregate US economy

¹Source: World Economic Outlook and BEA

²For more details on the sample of firms selected, see Appendix B.

³Since both accounts payable and receivable are likely to contain trade credit volumes from foreign transactions, I also calculate the share of the respective balance sheet item in US GDP adjusted for exports and imports, respectively. Then, accounts payable (receivable) make up approximately 4.4(5.9)% of US GDP including imports (exports). Notably, total R&D expenditures of the same sample of US firms account for less than 1% of US GDP. Overall, the [BIS \(2010\)](#) estimates that at a global scale two thirds of world trade are supported by inter-firm credit.

and are also consistent with related statistics documented in previous contributions by [Rajan and Zingales \(1995\)](#) and [Giannetti \(2003\)](#). Using a sample of non-financial European firms from 1993 to 1997 and a sample of G7 firms in 1991, respectively, [Giannetti \(2003\)](#) and [Rajan and Zingales \(1995\)](#) document that the share of accounts receivable in total assets ranges from 15 to 40% and the share of accounts payable in total liabilities from 15 to 60% of the average firm in their sample.⁴

2.1 Macroeconomic Features of Trade Credit

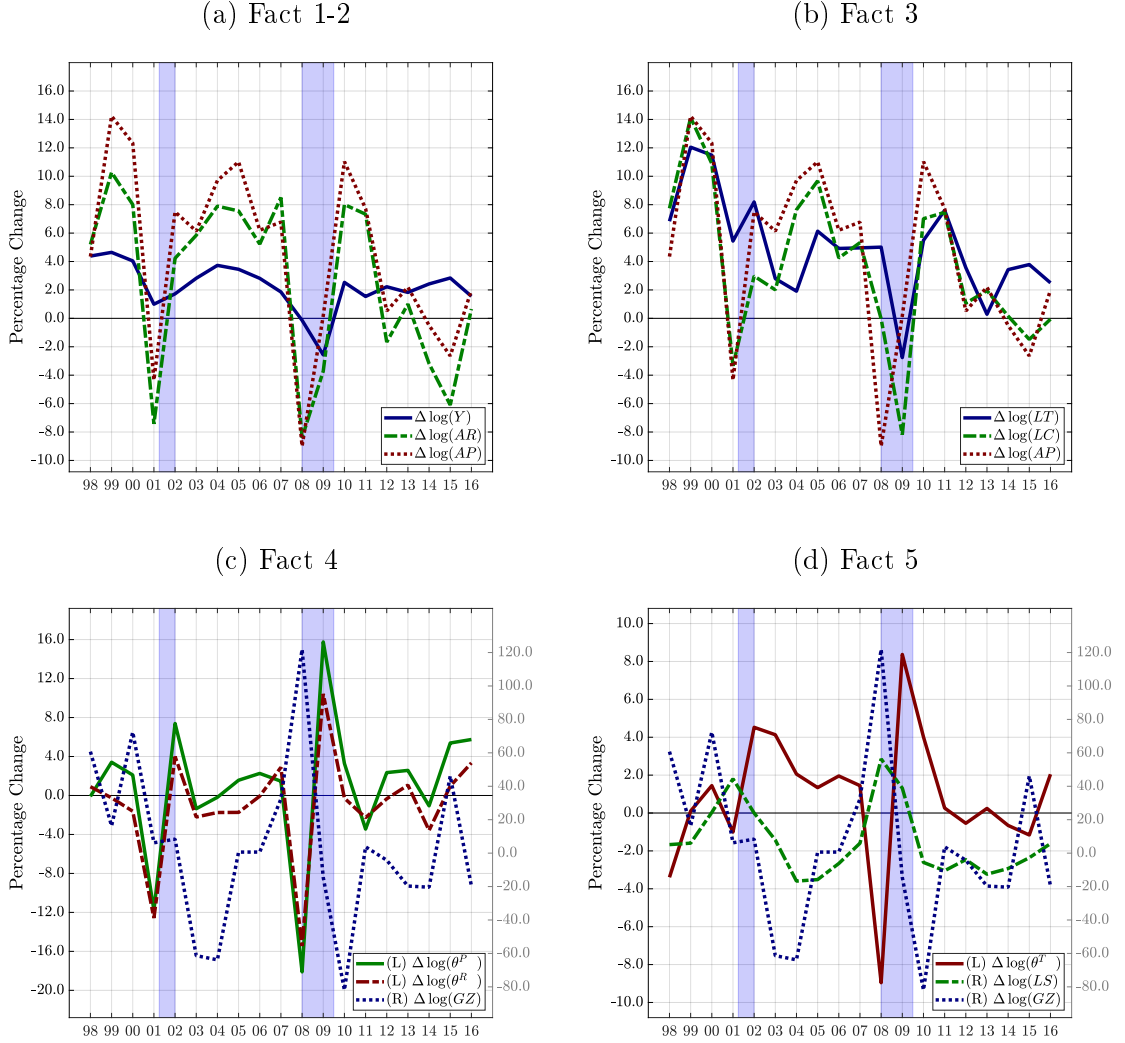
In the following, I first illustrate cyclical features of trade credit and its relation to other external financing sources such as bank and financial market debt in the US economy at an aggregate level for the time-period 1997-2016. For this purpose, I restrict the previously obtained panel of publicly-traded, non-financial US firms from Compustat to consist of firms with non-missing observations over the entire sample period only.⁵ Panel (a) of Figure 2.1 plots the log-changes of real GDP (Y), total accounts payable (AP) and accounts receivable (AR) in terms of 2007 dollars using the implied GDP-deflator provided by the BEA. Panel (b) presents the log-changes of real accounts payable and both, total (LT) and current (LC) liabilities. In addition, I also report the standard-deviation and the pairwise correlation of the respective series in Table 2.1. Panel (a) and (b) of Figure 2.1 highlight three business cycle features of trade credit in the US:

- (F1) The growth rate of the volume of trade finance is pro-cyclical with the growth rate of current real GDP. In other words, the growth rate of accounts payable and receivable increases during expansions and decreases during recessions.
- (F2) Trade credit is more volatile than the growth rate of total value added.
- (F3) Trade credit is more volatile than firms' total liabilities and exhibits a volatility of similar magnitude of current liabilities.

⁴Note that the balance-sheet decomposition presented in Table 2 in [Rajan and Zingales \(1995\)](#) and Table 3 in [Giannetti \(2003\)](#), respectively, is reported for the average firm in the corresponding sample rather than for the aggregate. The numbers presented in the main text are inferred from the statistics reported in either table.

⁵While the patterns remain the same qualitatively, restricting the sample ensures that the log-changes in the level of financial variables presented below are not the result of any changes in the composition of the sample. Nominal sales of the reduced sample represent approximately 19% of total gross output in the US. Total accounts payable (receivable) account for approximately 12.8(10.0)% of total liabilities (assets) of the same sample of firms and make up approximately 2.7(3.3)% of US GDP. Accounting for foreign trade implies that accounts payable (receivable) make up approximately 2.4(3.0)% of US GDP including imports (exports). Notably, total R&D expenditures of the same sample of US firms account for less than 0.3% of US GDP.

Figure 2.1: Business Cycle Properties of Trade Credit in the US



Note: The panels in this figure plot the evolution of the log-change in percent of aggregate US GDP (Y), Accounts Payable (AP), Accounts Receivable (AR), Total (LT) and Current (LC) Liabilities, the share of AP in Current Liabilities (θ^T), the aggregate credit spread index - GZ-spread (GZ) - derived in Gilchrist and Zakrajšek (2012), the net percentage of domestic banking institutions reporting a tightening of their standards for C&I loans (LS), the share of AP in Total Costs of Goods Sold (θ^P) and the share of AR in Total Sales (θ^R). All variables are reported in real terms using the aggregate price-index. The sample includes all Compustat firm-year observations from 1997 to 2016 of firms - excluding financial firms (NAICS 52 and 53) - with their head-quarter in the US and positive and non-missing observations of the respective variables of interest. The sample is further restricted to firms with non-missing observations over the entire time period 1997-2016, yielding a panel of 15,920 firm-year observations for 796 unique firms whose total nominal sales represent approximately 19% of total gross output in the US. For details on the sample used to generate these graphs, see Appendix B.

The same cyclical patterns of trade credit have been found in Cun et al. (2018) for a sample of Chinese industrial enterprises, which suggests similarities in the usage of trade credit of firms in advanced and emerging markets. (see i.a. Love et al., 2007; Love and Zaidi, 2010) In addition, it should be noted that the level of total accounts payable and receivable are strongly positively correlated. This should not come as a surprise as the same outstanding payment from a customer to its supplier will be recorded on the balance

sheet of both the customer as accounts payable and of the supplier as accounts receivable. Even though total accounts payable and receivable will not be equalized in the selected sub-sample of US firms, their dynamics track each other closely as one would expect from market clearing.

Table 2.1: Time Series Correlations 1997-2016

(a) Fact 1-2		Y_t	Y_t	AR_t	$\sigma(\%)$	(b) Fact 3		Y_t	LT_t	LC_t	$\sigma(\%)$
	Y_t	1.000			1.63		LT_t	0.606			3.42
	AR_t	0.614	0.614		5.85		LC_t	0.808	0.750		5.27
	AP_t	0.613	0.613	0.957	5.99		AP_t	0.613	0.505	0.822	5.99
(c) Fact 4		Y_{t+1}	θ_t^P	θ_t^R	$\sigma(\%)$	(d) Fact 5		Y_t	θ_t^T	LS_t	$\sigma(\%)$
	θ_t^P	0.454			6.80		θ_t^T	-0.172			3.43
	θ_t^R	0.435	0.965		5.42		LS_t	-0.569	-0.183		20.56
	GZ_t	-0.508	-0.384	-0.343	47.55		GZ_t	-0.038	-0.678	0.525	47.55

Note: Each subtable presents the pairwise correlations between the log-changes as well as the standard-deviation in percent of the log-changes of the time series plotted in the corresponding panel of Figure 2.1.

Trade versus Bank Credit. Given that the focus of this thesis is the role of trade credit for the transmission of liquidity shocks during the Great Recession, I now discuss the relationship between the usage of supplier and bank credit during this period of financial turmoil. For this purpose, I first obtain two aggregate measures of frictions in the financial market. The first measure is the aggregate credit spread index derived in [Gilchrist and Zakrajšek \(2012\)](#). The "GZ-spread" (GZ) is defined as the average difference in the yields on corporate bonds and yields on Treasury securities of comparable maturities and represents an important indicator of the degree of tensions in the financial system. The second measure reports the tightening in lending standards (LS) by banking institutions based on the [Senior Loan Officer Opinion Survey on Bank Lending Practices](#) conducted by the Federal Reserve. The series corresponds to the net percentage of domestic respondents tightening their standards for commercial and industrial (C&I) loans. Panel (c) of Figure 2.1 plots the log-change of the share of accounts payable in total costs of production and the share of accounts receivable in revenues at an aggregate level on the left axis as well as the change in logs of credit spreads on the right axis. As evident from Figure 2.1 and Table 2.1:

- (F4) The share of accounts payable and receivable in total costs of production and sales are negatively correlated with aggregate credit spreads in the economy.

In other words, as credit markets tighten, both the share of production costs financed using trade credit and the share of sales extended on trade credit decline. This highlights that the drop in the level of real accounts receivable and payable depicted in Panel (a) and

(b) was not driven by a pure reduction in demand but rather coincided with the tightening of credit markets, which preceded the decline in aggregate output. I then calculate the log-change of the share of accounts payable in current liabilities (θ^T) for the evolution of the composition of short-term borrowing. Panel (d) of Figure 2.1 plots both measures of financial frictions (right axis) as well as the log-change in the share of accounts payable in current liabilities (left axis). Together with the evolution of accounts payable, Figure 2.1d implies the following:

- (F5) As credit spreads rose and lending standards tightened at the onset of the financial crisis in 2008, liquidity in the supplier credit market contracted immediately and firms drew down their bank credit lines. The composition of short-term borrowing shifted towards bank credit as firms substituted supplier with bank credit.

This observation is consistent with the empirical evidence on the evolution of bank lending during 2008 documented in Ivashina and Scharfstein (2010) and on supplier credit presented in Costello (2017). Using data on syndicated loans from Reuter’s Dealscan, Ivashina and Scharfstein (2010) show that, while syndicated lending fell, C&I loans as reported on the balance sheets of US banks rose due to an increase in drawdowns of existing credit lines at the onset of the financial crisis. At the same time, receivables contracted significantly along the intensive margin as documented in Costello (2017) using detailed transaction data at a firm level in the US. Thus, the compositional shift of short-term borrowing towards bank credit in 2008 was due to the joint occurrence of the reduction in the provision of supplier credit and drawdowns of unused credit lines. However, the increase in C&I loans by approximately 17% in 2008 was followed by a sharp drop of 6.5% in 2009⁶, as the tightening of lending standards in 2008 translated into a considerable decline in the availability of new credit lines. Simultaneously, accounts payable and receivable increased such that the compositional shift reversed and firms substituted bank with trade credit as evident from Figures 2.1a and 2.1d.

A reasonable explanation for the differences in the speed of adjustment between credit markets in response to a deterioration of financial conditions is the contractual enforceability or rather the lack thereof in the case of supplier credit. While existing credit lines are prior commitments by banks to lend to corporations any amount up to a preset limit at prespecified rates (see Ivashina and Scharfstein, 2010), trade credit is not subject to formal contracts (see Cuñat, 2007). The empirical observation on the substitutability⁷ of supplier and financial market debt is consistent with the findings of a

⁶Source: Board of Governors of the Federal Reserve System (US), Commercial and Industrial Loans, All Commercial Banks [BUSLOANS], retrieved from FRED, Federal Reserve Bank of St. Louis; October 6, 2018

⁷It should be noted, that a few papers find evidence of a complementarity between bank and trade credit (see Giannetti et al., 2011) consistent with a theoretical argument of the signalling function of

large body of literature on the relationship between trade and bank credit over the business cycle starting with [Meltzer \(1960\)](#). It is argued that during a contractionary period, firms with access to liquidity will increase the amount of trade credit extended to customers, thereby providing funds to credit rationed firms. (see i.a. [Meltzer, 1960](#); [Schwartz, 1974](#); [Kohler et al., 2000](#); [Nilsen, 2002](#)) As a result, trade credit serves as a liquidity insurance across firms (see [Cuñat, 2007](#); [Wilner, 2000](#)). In particular, [Amberg et al. \(2016\)](#) show that firms manage liquidity shortfalls by increasing trade credit obtained from suppliers and rationing credit extended to customers.

Cost of Credit. These observed patterns further raise the following two questions: (a) Does the extension of trade credit affect a firm’s cost of bank credit? and (b) What is the relationship between the share of a firm’s cost of production financed by delaying payments to suppliers and the cost of credit? In order to address the first question, I relate to a strand of literature explicitly modelling financial intermediaries and incorporating credit markets into quantitative macro-models (see i.a. [Bernanke and Gertler, 1989](#); [Kiyotaki and Moore, 1997](#); [Bernanke et al., 1999](#); [Gertler and Kiyotaki, 2010](#)). While a detailed discussion thereof is beyond the scope and purpose of this thesis, I exploit the fact that the interest rate on bank loans faced by firms and determined in equilibrium will be an increasing function of (default) risk in the economy. (see e.g. [Bernanke et al., 1999](#)) Since firms that sell their products on credit are subject to the credit risk of their customers (see [Jacobson and von Schedvin, 2015](#); [Costello, 2019](#)), I now investigate to what extent the risk premium affecting the cost of bank loans (r_k^Z) is positively correlated with the share of accounts receivable in total sales (θ_k^R). For this purpose, I estimate the following equation

$$\ln(r_{kt}^Z) = \beta_0 + \beta_1 \ln(\theta_{kt}^R) + \sum_{v=2}^V \beta_v X_{vk,t} + FE + \epsilon_{kt} \quad (2.1a)$$

using a panel of 45 sectors from 2000 to 2014 due to the data-limitations at a firm level. As a baseline measure for the risk premium, I employ the sectoral credit spreads (r_{kt}^Z) derived in [Gilchrist and Zakrajšek \(2012\)](#) and provided to me by the authors. The remaining financial variables are calculated by aggregating firm level data of a panel of Compustat firms and include: the share of accounts receivable in total sales at a sector level (θ_{kt}^R), the leverage ratio (LV_{kt}^S), the ratio of current to long-term debt (θ_{kt}^F), the share of cash in total production cost (θ_{kt}^E) as well as the relative size of a sector ($Size_{kt}$) measured by the share of a sector’s assets in total assets. A detailed description of the variables and the dataset is provided in [Appendix B](#). Equation [2.1a](#) is estimated by OLS including sector

trade credit on the solvency of borrowers (see [Biais and Gollier, 1997](#)). In other words, the extension of trade credit conveys a positive signal on the creditworthiness of a customer, which induces banks to lend. The co-existence of the substitutability and complementarity of bank and trade credit and its cyclical pattern is investigated further in a recent contribution by [Huang et al. \(2011\)](#).

and year fixed effects. The estimated coefficients and corresponding clustered standard errors at the sector level are reported in Table 2.2a.

Table 2.2: Bank versus Trade Credit

(a) Cost of External Finance					(b) Trade Credit Shares			
VAR	(1)	(2)	(3)	(4)	VAR	(1)	(2)	(3)
$\ln(\theta_{kt}^R)$	0.33*	0.33*	0.34*	0.32*	r_{kt}^B	0.12+	0.13+	0.12+
	(0.161)	(0.157)	(0.153)	(0.151)		(0.064)	(0.063)	(0.062)
$\ln(LV_{kt}^S)$	0.03	0.03	0.04	0.03	θ_{kt}^F	-0.03	-0.03	-0.03
	(0.122)	(0.122)	(0.121)	(0.120)		(0.022)	(0.021)	(0.021)
θ_{kt}^F		0.33+	0.32+	0.31+	θ_{kt}^E		-0.02	-0.02
		(0.167)	(0.166)	(0.163)			(0.055)	(0.056)
θ_{kt}^E			0.57	0.64	C_{kt}^X			-0.02*
			(0.457)	(0.452)				(0.010)
$Size_{kt}$				2.98*				
				(1.331)				
NObs	579	579	579	579	NObs	579	579	579
R2	0.76	0.77	0.77	0.77	R2	0.79	0.79	0.80
Constant	Yes	Yes	Yes	Yes	Constant	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes	Yes	Sector FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Year FE	Yes	Yes	Yes

Note: Panel (a) and (b) report the estimated coefficients of Equation (2.1a) and (2.1b), where the dependent variables are: (a) sectoral credit spreads ($\ln(r_{kt}^Z)$) derived in Gilchrist and Zakrajšek (2012) and (b), the share of accounts payable in total cost of production (θ_{kt}^P). The set of control variables at a sector level derived from a panel of Compustat firms includes: the share of accounts receivable in total sales (θ_{kt}^R), the leverage ratio (LV_{kt}^S), the ratio of current to long-term debt (θ_{kt}^F), the share of cash in total production cost (θ_{kt}^E), the relative size of a sector ($Size_{kt}$) measured by the share of a sector's assets in total assets and detrended total production costs (C_{kt}^X). A detailed description of the variables and the dataset is provided in Appendix B. The estimated coefficients are derived by estimating Equation (2.1a) and (2.1b) by OLS including both sector and year fixed effects. Clustered standard errors at the sector level are reported in parentheses, ** p<0.01, * p<0.05, + p<0.1

The estimation results of Equation (2.1a) suggest a positive relationship between the credit spread and the share of accounts receivable in total sales such that a one percent increase of the shares of revenues obtained on credit significantly increases a sector's risk premium by approximately 0.3 percent. These results are robust to the inclusion of additional variables ($\{X_v\}_{v=1}^V$) in order to control for the access to external funds, the ability of firms to repay their debt and the size of the firm following related empirical work by e.g. Petersen and Rajan (1997); Jacobson and von Schedvin (2015); Costello (2017). Having established a positive relationship between trade credit extended to customers and credit spreads, I now turn to the second question by estimating the relationship between the share of production costs financed using trade credit (θ_{kt}^P) and the cost of bank credit (r_{kt}^B)

$$\theta_{kt}^P = \beta_0 + \beta_1 r_{kt}^B + \sum_{v=2}^V \beta_v X_{vk,t} + FE + \epsilon_{it} \quad (2.1b)$$

using the same panel of 45 sectors from 2000 to 2014 as before. Since price data on the cost of trade credit are not readily available due to the nature of the contract, I limit the analysis to the interest rate on bank loans which are approximated by calculating the sum of the federal funds rate and the sectoral credit spread (r_{kt}^Z) derived in [Gilchrist and Zakrajšek \(2012\)](#). In addition, the inclusion of the detrended total cost of inputs (C_{kt}^X) allows me to control for the size of each sector in terms of their production costs. Equation (2.1b) is also estimated by OLS including sector and year fixed effects. The estimated coefficients and corresponding clustered standard errors at the sector level reported in [Table 2.2b](#) suggest a significant and positive relationship between the cost of bank credit and the share of production costs financed by postponing payments to suppliers: An increase in the cost of bank credit by 100 basis points ($r_{kt}^B + 0.01$) increases the share of production costs financed using trade credit by 0.12 percentage points. This empirical evidence is in line with the strand of literature modelling bank and trade credit as substitutes, which will be exploited in the set up of the model presented in [Chapter 3](#). In the last paragraph of this subsection, I now discuss the heterogeneous usage of trade credit across firms in the US economy.

Heterogeneity in Trade Credit Usage. While the dynamics of log-changes of total payables and receivables presented in [Figure 2.1](#) are informative for the business cycle properties of trade credit, they contain little information on the heterogeneity of the usage of trade credit across firms. In order to provide a summary measure of the trade credit usage of a firm from both its perspective as a lender and a borrower, I first define the net-lending position of firm k (θ_{kt}^τ).

Definition 2.1. *The net-lending position of a firm k is defined as the ratio of total trade credit extended to customers (accounts receivable) and the difference between total cost of production and trade credit obtained from suppliers (accounts payable).*

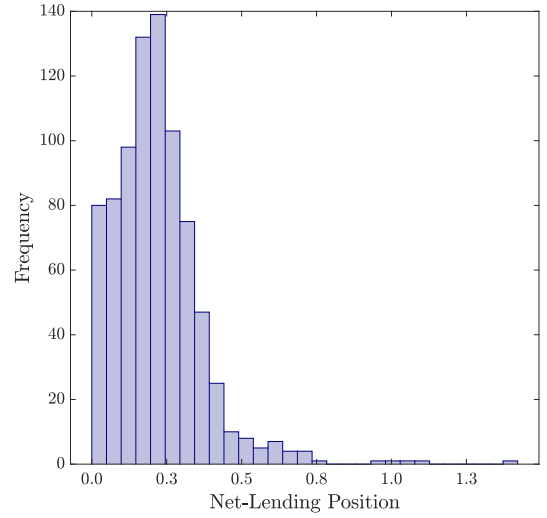
In other words the net-lending position reflects a firm's ability to extend trade credit to their customers and obtain trade credit from their suppliers: How many future dollars does firm k receive per dollar it needs to finance today. An increase in the net-lending position of firm k implies that firm k extends relatively more trade credit to its customers (accounts receivable) compared to its total cost of production net of trade credit (accounts payable) obtained from its suppliers. [Figure 2.2](#) plots the distribution of the average net-lending position in 2004-2007 of the same sample of Compustat firms used to generate the respective graphs shown in [Figure 2.1](#). Since the distribution of the net-lending position is skewed to the left, there is heterogeneity in the trade credit usage of US firms. In

particular one key pattern of trade credit usage by US firms emerges:

- (F6) The majority of US firms extends less trade credit than their own financing needs to cover their production costs net of trade credit obtained from suppliers. Only a few act as financial intermediaries by extending relatively more trade credit to customers.

By taking a closer look at the industry-affiliation of firms, it becomes apparent that firms which are more upstream in the production chain (e.g. primary-industries, manufacturing) tend to have a higher net-lending position than more downstream firms (e.g. retail, services). This observation highlights that the structure of inter-sectoral trade plays a crucial role in determining which aspect of trade finance dominates and confirms the findings in [Kalemli-Özcan et al. \(2014\)](#), that upstream firms have higher accounts receivable compared to final product firms. The relationship between the net-lending position of firms (sectors) and the production network will be investigated in more detail in [Section 4.1](#), in the context of the calibration of the model introduced in [Chapter 3](#).

Figure 2.2: Trade Credit Usage of US Firms



Note: The figure plots the distribution of the average net-lending position defined as the ratio of accounts receivable and the difference between total cost of production and accounts payable over 2004-2007 of the sample of Compustat firms described in [Appendix B](#).

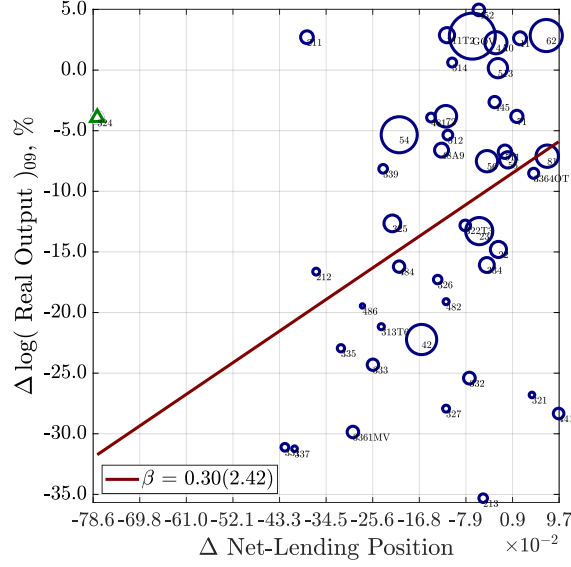
Having presented statistics on the business cycle properties on trade credit at an aggregate level, the evolution of the composition and heterogeneity of short-term borrowing, it becomes apparent that trade credit is an important source of short- to medium term credit as an alternative to bank finance used by all types of firms and therefore plays a crucial role for the propagation of shocks in an economy. As the focus of this thesis is the role of trade credit linkages for the transmission of financial shocks and consequently its effect on sectoral and aggregates outcomes, the next subsection further investigates the relationship between the usage of trade credit by US sectors and the drop in sectoral output during the 2008-2009 Financial Crisis.

2.2 Trade Credit and Output Growth during the 2008-2009 Financial Crisis

As already mentioned in the introduction, previous empirical contributions by [Jacobson and von Schedvin \(2015\)](#) and [Costello \(2017\)](#) - among others - have emphasized the role of trade credit linkages for the propagation of financial shocks and its effect on firm level outcomes. While [Jacobson and von Schedvin \(2015\)](#) focus on the role of trade credit linkages as a transmission mechanism of bankruptcies, [Costello \(2017\)](#) highlights that in response to a banking shock, firms adjust their trade credit contracts by being more selective in their lending behavior and thus generate asymmetric adverse effects on their customers' access to liquidity. This thesis contributes to the literature by focusing on different and counteracting mechanisms through which trade credit can affect economic outcomes at a macro-level, while emphasizing the role of firms as financial intermediaries in an economy for aggregate and sector level outcomes. In particular, I propose a new summary measure - the net-lending position of a sector defined in [2.1](#) - which relates a firm's/sector's engagement in financial intermediation to their own financing needs and thus captures the relative importance of a firm as a recipient and lender of credit in an economy. Following the discussion in the previous section, this section elaborates on how differences in the usage of trade credit across firms has affected sectoral outcomes during the recent financial crisis, by investigating simple correlation patterns.

The first question that arises from the literature is: How did the drop in liquidity in the market for trade credit affect sectoral output growth during the crisis? In order to address this question, [Figure 2.3](#) plots the change in sectoral real output in 2009 against the change in a sector's net-lending position in 2008. In addition, the estimated coefficient of a simple OLS regression and corresponding T-statistic are also reported, while excluding outliers if applicable. A simple inspection of [Figure 2.3](#) and the implied correlations suggests that: Sectors experiencing a sharper decline in their net-lending position in 2008 also experienced a stronger decline in output in 2009. Note that the decline in a sector's net-lending position implies a stronger decline in trade credit extended relative to their own requirements of funds net of trade credit obtained from suppliers, to finance their cost of production. Overall, this observation suggests that changes in a sector's relative usage of trade credit are correlated with its economic performance during the crisis, which is in line with the findings in the broader literature.

Figure 2.3: Change in Trade Credit and Sectoral Output Growth in 2009



Note: This figure plots the change in sectoral real output in 2009 against the change in a sector's net-lending position in 2008, based on Definition 2.1. The estimated coefficient of a simple OLS regression and corresponding T-statistic are also reported, while excluding outliers if applicable. Outliers excluded from the regression are represented by a green triangle. The size of one observation represents the relative importance of the sector in the economy measured by the share of a sector's average pre-crisis (2004-2007) value added in total value added.

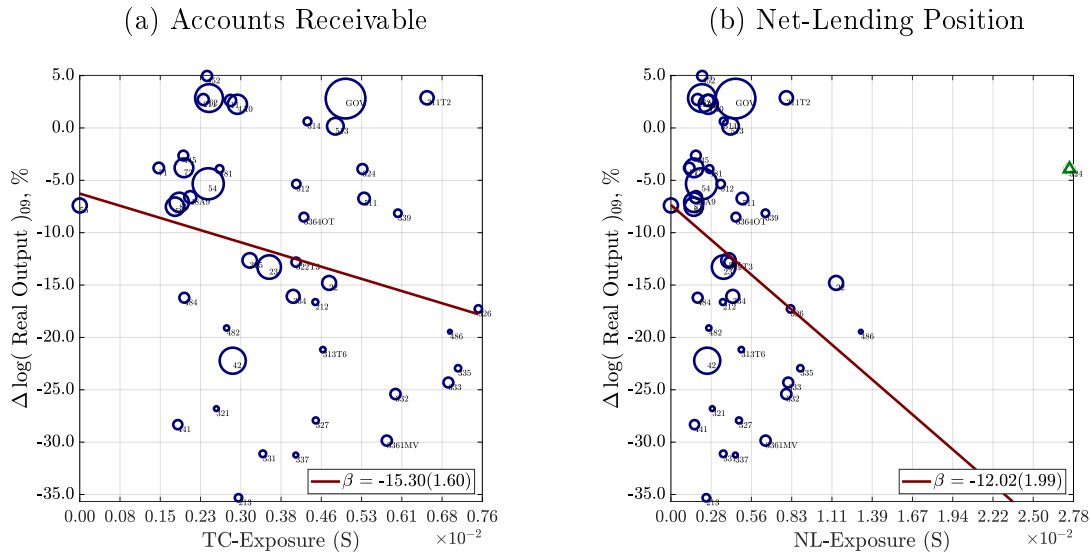
While the previous statement emphasizes the relationship between a sector's *own* trade credit usage and its output response, the second question that follows is, how a sector's *exposure* to the trade credit usage of its suppliers and customers affected its outcome during the 2008-2009 financial crisis. For this purpose, I first construct the following measure of exposure to suppliers.

$$e_k^R = \sum_{m=1, m \neq k}^M w_{km}^R \frac{AR_m}{R_m}, \text{ where } w_{km}^R = \frac{AP_k}{Cost_k} \left(\frac{p_m x_{km}}{R_k} \right). \quad (2.2)$$

From the perspective of sector k , the exposure measure is calculated as the weighted sum of its suppliers' share of accounts receivable in total sales. By using the accounts receivable shares of suppliers, this captures the extent to which suppliers of sector k engage in inter-firm financial intermediation and are therefore more exposed to changes in the cost of bank finance, as suggested by the regression results presented in Table 2.2a. The weights (w_{km}^R) are a combination of sector k 's expenditure share on inputs purchased from supplier m and sector k 's overall dependence on trade credit to finance its production. The weights need not sum up to one but capture the dependency of sector k on supplier m as a supplier of inputs and trade credit. Furthermore, note that due to data limitations, I use aggregate rather than link-specific measures trade credit. The exposure variables with respect to the net-lending position are calculated as shown above with the trade credit shares of suppliers replaced with their net-lending position.

Figure 2.4 then plots sectoral output growth during the crisis against the four-year (2004-2007) pre-crisis average of the respective exposure measure. The correlation patterns shown in Figure 2.4 suggest that sectors who were more exposed to suppliers with a larger receivable share in their netsales and/or a higher net-lending position experienced a larger decrease in output during the financial crisis after the shock.⁸ This observation is in line with the findings in the empirical literature and highlights that sectors are not only directly affected by changes in the liquidity in the market for trade credit but are also affected indirectly through production and financial linkages as measured by their pre-crisis exposure to trade credit.

Figure 2.4: Output Growth and Exposure to Trade Credit of Suppliers



Note: This figure plots sectoral output growth in 2009 against a sector's average pre-crisis (2004-2007) exposure to (a) the accounts receivable shares of its suppliers (e_k^R) defined in Equation (2.2) and (b) the net-lending position of its suppliers. The fitted line of an OLS-regression and corresponding coefficient and T-statistic are also reported. If applicable, outliers excluded from the regression are represented by a green triangle. The size of one observation represents the relative importance of the sector in the economy measured by the share of a sector's average pre-crisis (2004-2007) value added in total value added.

2.3 Concluding Remarks

This chapter has discussed the cyclical properties of supplier credit as well as the heterogeneity in the lending and borrowing behavior across firms. In particular, the data suggest that liquidity in the market for trade credit was severely affected the onset of the 2008-2009 Financial Crisis inducing a shift of the composition of short-term credit towards bank finance. In order to capture the heterogeneity of trade credit usage across firms, I propose a novel credit measure - the net-lending position of a firm - defined as the ratio of trade credit extended to customers and total production costs net of trade

⁸The exposure measure to customers is constructed analogously to Equation (2.2) and yields similar results as shown in Appendix B.

credit obtained from suppliers. The majority of US firms extend less trade credit than their own financing needs, while only a few act as financial intermediaries by extending relatively more trade credit to customers. Furthermore, I find a positive correlation between the decline in sectoral output during the crisis and a sector's overall dependency on supplier credit, suggesting that trade credit linkages affect the transmission of financial shocks and thus the real economy. Overall, trade credit represents an important source of financing for all types of firms and affects the propagation of shocks and thereby sectoral and aggregate outcomes.

In the next chapter I now build a model, which focuses on the contraction of the liquidity in the trade credit market at the onset of the financial crisis in order to investigate the role of credit linkages in the propagation of the financial shock. To this end, I abstract from any dynamics by imposing the timing restriction that financial markets contracted at the same time as aggregate output such that the share of accounts payable (receivable) in total production costs (sales) is now positively correlated with current rather than next period's output. Although output declined with a time lag in response to the deterioration of credit conditions as shown in Figure 2.1a, this simplification may be justifiable as (1) the sharp increase in credit spreads occurred in the second half of 2008 and (2) a firm's production plans and therefore intermediate demand might be pre-determined. This allows me to focus on the effect of a decline in supplier credit on aggregate output during the crisis. In particular, I build a model in which firms face working capital constraints and finance their input expenditures using both bank- and supplier credit. At this point it should be noticed that, in order to keep the model tractable, I only consider a firm's trade credit decision along the intensive rather than the extensive margin. In other words, I do not explicitly model a firm's decision to enter the trade credit market in the first place. A growing theoretical literature, as highlighted in the introduction, investigates both the characteristics and motives of firms to engage in financial intermediation. A detailed overview of the different strands of the theoretical literature is provided in [Cuñat and García-Appendini \(2012\)](#) and is beyond the scope of this thesis. I now describe the set-up of the model.

Chapter 3

A Multisector Model with Financial Frictions

In this chapter, I introduce a static¹ quantitative multisector model in the tradition of Long and Plosser (1983) with trade in intermediate inputs and endogenous credit linkages between sectors. Representative firms in each sector face working capital constraints and finance their input expenditures using both bank and supplier credit, while being subject to sectoral productivity and financial shocks to the cost of bank credit. The model nests the economy introduced in BL(2017) if no credit linkages are considered. The main novelty in this set-up is the introduction of endogenous credit linkages along the intensive margin among sectors by, in contrast to previous work by Zhang (2017) and Luo (2018), explicitly modelling the price of trade credit as well as introducing a direct link between the cost of bank finance and the amount of trade credit extended to customers, as outlined in the introduction. The model set-up is as follows.

Production Structure. The economy consists of M intermediate sectors indexed by $k = 1, \dots, M$ producing M differentiated goods, a final good sector indexed by 0 producing a composite final good and a representative household. A continuum of perfectly competitive firms within each sector produce an identical good using the same technology such that there exists a representative firm per sector. Therefore, I use the words firm and sector interchangeably. The production structure of the economy is depicted in Figure 3.1. An *intermediate goods* firm k produces output, q_k , using capital, k_k , productive labor, ℓ_k^Q , and a composite of intermediate inputs, X_k , with the Cobb-Douglas technology

$$q_k = \left(A_k k_k^{\alpha_k \eta_k} V_k^{1 - \alpha_k \eta_k} \right)^{\chi_k} \quad (3.1)$$

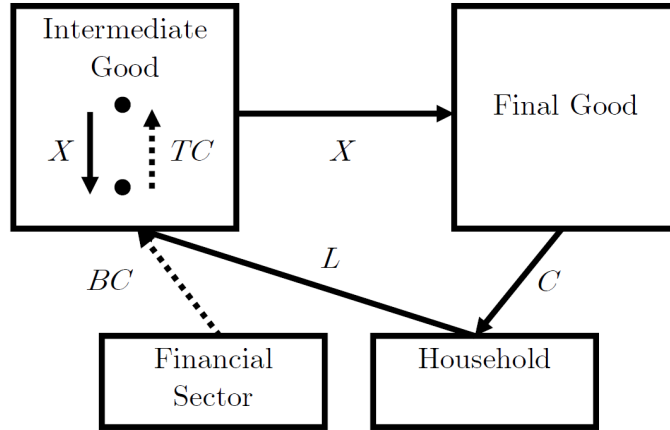
¹By abstracting from savings and investment dynamics, this thesis focuses on cross-sectional propagation patterns, which also have been the focus of a recent strand of literature see Bigio and La'O (2017), Baqaee and Farhi (2018) and Baqaee and Farhi (2019) among others.

where the composite of (productive) labor and intermediate inputs, V_k , as well as the composite of intermediate inputs, X_k are defined as

$$V_k = \bar{A}_k^V \left(\ell_k^Q \right)^{v_k} \left(X_k \right)^{1-v_k} \quad \text{and} \quad X_k = \bar{A}_k^X \prod_{s=1}^M x_{ks}^{\omega_{ks}^X}. \quad (3.2)$$

While A_k denotes sector-specific productivity and is subject to productivity shocks, \bar{A}_k^V and \bar{A}_k^X represent normalization constants as a function of the production parameters introduced to simplify the equilibrium expressions derived below. The intermediate production technology exhibits decreasing returns to scale (DRS), $\chi_k \in (0, 1)$, in its production inputs. Due to the Cobb-Douglas technology, the production parameter $\omega_{ks}^X \in [0, 1]$ denotes the share of good s in the total intermediate input use of sector k and it is assumed that $\sum_{s=1}^M \omega_{ks}^X = 1 \quad \forall k \in \{1, \dots, M\}$. The output of firm k is used both as an intermediate input in production and to produce a composite final good F consumed by the household such that $F = C$ holds in equilibrium.

Figure 3.1: Flow Chart of the Model Economy



Note: The figure depicts the flow of intermediate goods (X), the final consumption good (C), labor (L) as solid lines, and the flow of supplier (TC) and bank credit (BC) as dashed lines.

The final good firm assembles the consumption good using the constant returns to scale (CRS) technology

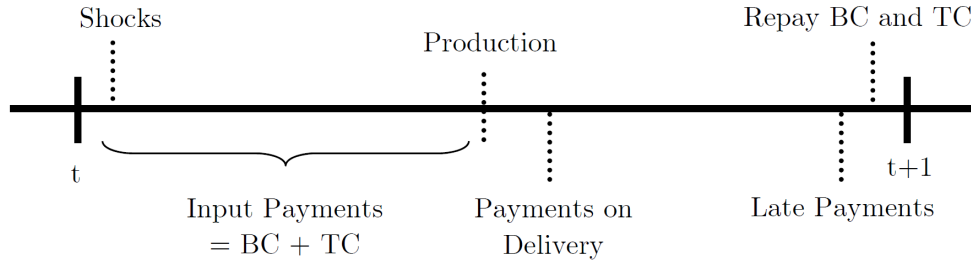
$$F = A_0 \prod_{m=1}^M x_{0m}^{\omega_m^F} \quad (3.3)$$

with productivity A_0 , where $\sum_{m=1}^M \omega_m^F = 1$. Similarly, the production parameters $\omega_m^F \in [0, 1]$ denote the expenditure share on good m by the final good firm. Productivity in the intermediate and final sector is subject to sector-specific, normally distributed shocks, z_i^q , and is given by $A_i = \exp(z_i^q) \bar{A}_i \forall i \in \{0, 1, \dots, M\}$. The sector-specific normalization constants, \bar{A}_i , are functions of the respective production parameters introduced for analytical

convenience and are defined in Appendix C. For the purpose of the model, I assume that $z_0^q = 0$ such that I am abstracting from any shocks to final demand. I now impose the following constraint for intermediate good producing firms.

Assumption 3.1 (Working Capital Constraint). *The production and delivery of products along the supply chain is such that any sales are only realized after production has taken place.*

Figure 3.2: Timing of the Intermediate Good Firm's Problem



The timing of events is depicted in Figure 3.2 and is as follows: At the beginning of a period both productivity (z_k^q) and financial shocks to the cost of bank credit (z_k^b) are realized such that there is no idiosyncratic or aggregate uncertainty in the model. Within period I consider two stages: the pre-production stage and the post-production stage. Due to the working capital constraint, firms make their production and borrowing portfolio decisions prior to producing their output. Once firms produced, they sell their output to both intermediate and final good producers and retrieve the share of sales paid on delivery. At the end of the period, firms repay their debt obligations and receive the remaining share of revenues.

Financing Production. The representative intermediate good producing firm in sector k faces a cash flow mismatch between input payments at the beginning of the period and the realization of revenues. Wlog, I assume that firms have no internal funds available such that firm k needs to finance its working capital using

- (1) an intraperiod bank loan, BC_k , at an interest rate r_k^B , and
- (2) trade credit from its suppliers (net accounts payable)² at an interest rate r_s^T

$$AP_k = \sum_{s=1}^M AP_{ks} = \sum_{s=1}^M \theta_{ks} p_s x_{ks} \quad (3.5)$$

²Similarly, AR_k is the total amount of trade credit extended to firm k 's customers (net accounts receivable)

$$AR_k = \sum_{c=1}^M AR_{ck} = \sum_{c=1}^M \theta_{ck} p_k x_{ck} \quad (3.4)$$

where $\theta_{ks} \in [0, 1]$ represents the share of payments to supplier s that firm k postpones paying until after its sales are realized. As evident from Equation (3.5), firms can only postpone payments to intermediate good suppliers while any productive (ℓ_k^Q) and non-productive (ℓ_k^T) labor expenditures have to be paid upfront. Therefore, labor costs will be financed using bank credit only since firms are assumed to have no internal funds. Thus, the financial constraint of firm k can be written as

$$w \left(\ell_k^Q + \ell_k^T \right) + \sum_{s=1}^M p_s x_{ks} \leq BC_k + AP_k \quad (3.6)$$

which is binding in equilibrium. At this point, it should be noted that I abstract from a micro-foundation of the incentives of firms to engage in financial intermediation in the form of trade credit in the first place, which has been investigated in theoretical contributions by Emery (1984), Smith (1987), Biais and Gollier (1997), Burkart and Ellingsen (2004), Cuñat (2007) among others. (see e.g. Cuñat and García-Appendini, 2012, for an overview) I now introduce two additional simplifying assumptions, which allow me to capture the following two main features of the relationship between bank and trade credit presented in Chapter 2 while ensuring the analytical tractability of a firm's optimization problem: (1) A firm's short-term credit portfolio is composed of both bank and supplier credit; and (2) The cost of bank credit are increasing in the share of sales extended on trade credit to customers. Both assumptions are discussed in greater detail below.

Assumption 3.2 (Management Cost of Credit Lines). *Firms face additional management costs of credit lines in the form of a non-productive labor input (ℓ_k^T).*

Assumption 3.3 (Cost of Bank Credit). *The cost of bank credit (r_k^B) is an increasing function in the share of total sales extended on trade credit to customers (θ_k^C).*

Management Costs of Credit Lines. In order to manage its credit lines, a firm needs to hire non-productive labor (e.g. accountants, sales people and managers), $w\ell_k^T$, which introduces an additional cost component into the firm's problem. The adjustment of a firm's credit portfolio is subject to a combination of convex and non-convex frictions. Formally, the total costs of managing credit lines is given by

$$C_k^T(\{\theta_{ks}\}_s) = w\ell_k^T = \kappa_k^B + \sum_{s=1}^M \kappa_{0,ks}^T \theta_{ks} + \frac{\kappa_{1,ks}^T}{2} \left(\frac{\theta_{ks} - \bar{\theta}_k^S}{\bar{\theta}_k^S} \right)^2 \quad (3.7)$$

where I adapt the findings of a strand of literature related to the functional form of the adjustment costs of capital (see Cooper and Haltiwanger, 2006). The term $\bar{\theta}_k^S$ denotes the average share of intermediate input payments obtained on trade credit. The first term implies that there are fixed costs, κ_k^B , involved in managing credit lines such that even if sector k does not obtain any supplier credit, it still faces fixed management costs. Similar

to Luo (2018), the quadratic adjustment cost part captures the fact that it is costly to change the credit composition. In addition, I further assume that while $\{\kappa_{1,ks}^T\}_s \forall k$ is always positive, the linear cost parameter, $\kappa_{0,ks}^T$, may take on both positive and negative values. This should highlight, that in adjusting the credit relationship with one's supplier s , firm k may undergo an organizational restructuring of its supplier relationship thereby increasing (e.g. switching suppliers within sector) or decreasing (e.g. intensifying the business relationship) the management costs. Notably, I assume the variable adjustment cost parameters to be specific to a firm-supplier pair.

At this point, it should be noted that in the absence of uncertainty³ from the model and allowing for a frictionless adjustment of the credit portfolio, the choice between bank and supplier credit will be such that firms will finance their expenditures using only the cheapest credit source. While at the individual firm and transaction level this is a reasonable outcome - e.g. a firm either settles its payment on delivery ($\theta_{ks} = 0$) or not ($\theta_{ks} = 1$) - a mixture of both bank and trade credit is maintained at the sector level as highlighted in Chapter 2, even if the interest costs of bank finance might be cheaper than supplier credit as discussed in Cuñat and García-Appendini (2012). Therefore, the introduction of non-linear adjustment costs of credit lines ensures that the representative firm in each sector optimally chooses a credit portfolio of both bank and supplier credit consistent with the empirical evidence presented in Chapter 2, while maintaining the tractability of the model in the absence of uncertainty.

Costs of Bank Credit . Taking into account the empirical observations on the relationship between the cost of bank credit and trade credit extended to customers presented in Chapter 2, I introduce the banking sector in a reduced form by imposing the following functional form on the interest rate charged on bank credit

$$r_k^B = \pi_0^B + r_k^Z = \pi_0^B + \exp(z_k^b)(\theta_k^Z)^\mu \pi_0^B, \text{ where } \theta_k^Z = \bar{\theta}_0^D + \theta_k^C \quad (3.8)$$

and $\frac{\partial r_k^B}{\partial \theta_k^C}, \frac{\partial^2 r_k^B}{(\partial \theta_k^C)^2} > 0$. In other words, I assume that each sector is charged a risk premium, r_k^Z , over the federal funds rate, π_0^B , which is a convex function in the average trade credit share extended to firm k 's customers, θ_k^C . The additional parameter, $\bar{\theta}_0^D$, is introduced to ensure that the equilibrium interest rate on trade credit is well behaved and of similar magnitude relative to the cost of bank credit as documented in the literature (Cuñat and García-Appendini, 2012). The parameter, $\bar{\theta}_0^D$, will be calibrated to the average leverage in the economy, thereby capturing a notion of aggregate default probability affecting the overall cost of bank credit. While the positive relationship between the interest rate charged on bank loans and the probability of default is a common modelling assumption (see i.a. Khan et al., 2016) and is supported by empirical evidence (see i.a. Angbazo,

³In models where agents face a portfolio choice between e.g. equities (see e.g. Engel and Matsumoto, 2006), agents typically maintain a mixed portfolio, due to the existence of uncertainty.

1997), I abstract from including a micro-foundation thereof in order to keep the model tractable, while capturing observed empirical patterns on the interdependency of the cost of credit. Clearly, this set up introduces a direct upstream credit link between the cost of bank credit of firm k and trade credit extended to its customers: the higher the share of delayed payments by firm k 's customers, the higher the interest rate on bank credit that firm k is charged. I am now able to formulate the intermediate good firm's profit maximization problem.

Intermediate Production. Firms are price takers in both goods and credit markets. I assume that in the short-run capital is exogenously given and at its steady state value, \bar{k}_k . The objective of the representative firm in sector k is to choose production inputs, the credit portfolio as well as the optimal level of production and the share of its sales to extend on trade credit to maximise profits, while taking demand as given. Therefore, the set of choice variables is given by $\mathcal{V} = \{\ell_k^Q, \{x_{ks}\}_{s=1}^M, V_k, \{\theta_{ks}\}_{s=1}^M, \theta_k^C\}$. Taking into account the production (3.13) and credit (3.14) feasibility constraints, the intermediate good firm k 's profit maximization problem can be formulated as

$$V(z_k^q, z_k^b) = \max_{\mathcal{V}} \pi_k, \text{ st } \pi_k = (1 + r_k^T \theta_k^C) p_k q_k - (1 + r_k^B) BC_k - \sum_{s=1}^M (1 + r_s^T) AP_{ks}, \quad (3.9)$$

the production function (3.1), total bank (3.6) and supplier credit (3.5), the credit management cost function (3.7), the interest rate on bank credit (3.8), feasibility constraints on trade credit shares $\theta_k^C, \theta_{ks} \forall s \in [0, 1]$ and non-negativity constraints $\ell_k^Q, x_{ks}, V_k \geq 0 \forall s$. (see Appendix C.3.2 for details)

Final Demand. The representative final good producer is required to pay its input expenditures at the time of the delivery of the product. Since I assume that the final goods producer does not face any working capital constraints, the profit maximization problem is simply given by

$$\max_{\{x_{0m}\}_m} PF - \sum_{m=1}^M p_m x_{0m} \quad (3.10)$$

subject to the production function (3.3) and a non-negativity constraint $x_{0m} \geq 0 \forall m$. The household chooses consumption expenditures, C , and labor supply, L , to maximize utility

$$U(C, L) = \frac{C^{1-\epsilon_C}}{1-\epsilon_C} - \frac{L^{1+\epsilon_L}}{1+\epsilon_L}. \quad (3.11)$$

subject to the budget constraint

$$PC \leq wL + \sum_{m=1}^M \pi_m + \sum_{m=1}^M r_m^B BC_m. \quad (3.12)$$

The parameter $\epsilon_C > 0$ denotes the income elasticity and $\epsilon_L > 0$ denotes the inverse

Frisch elasticity of labor supply. The budget constraint of the household indicates that total income of the household - total wage bill, profits and interest income from extending bank credit to firms - is spent on the aggregate consumption good. Ultimately, I assume that banks are owned by foreign households such that any interest rate income, while initially rebated to households, is treated as an import in the calculation of aggregate GDP.

Market Clearing. As depicted in Figure 3.1 the intermediate good of sector k is used both in the production of intermediate goods as well as in the production of the final good such that market clearing for sector k requires that

$$q_k = \sum_{c=0}^M x_{ck}. \quad (3.13)$$

The labor market clears if $L = \sum_{k=1}^M \ell_k^Q + \ell_k^T$ holds. Similarly, the interest rate on trade credit charged by sector k in equilibrium is such that

$$AR_k = \theta_k^C p_k q_k = \sum_{c=0}^M \theta_{ck} p_k x_{ck} = \sum_{c=0}^M AP_{ck} \quad (3.14)$$

holds. In other words, total accounts receivable of sector k equal total accounts payable owed by its customers to sector k . A competitive equilibrium in this economy is then defined as

Definition 3.1. *A competitive equilibrium in this economy is a set of aggregate and sector level prices $(w, P, \{p_m, r_m^T\}_{m=1}^M)$, quantities $(C, F, L, \{q_m, \ell_m^Q, x_{0m}, \{x_{ms}\}_{s=1}^M\}_{m=1}^M)$ and sector level trade credit shares $\{\theta_m^C, \{\theta_{ms}\}_{s=1}^M\}_{m=1}^M$ such that*

- (1) *The representative household maximizes utility.*
- (2) *Intermediate and Final-Good producers maximize profits.*
- (3) *Goods and Factor markets clear.*
- (4) *Financial markets clear.*

3.1 Equilibrium Characterization

Having introduced the model-set up in the previous section, I now discuss the effect of working capital constraints and credit links on the optimal intermediate input choice and credit composition before characterizing the equilibrium of the economy.

Firm Optimality and Credit Composition. In particular, I first describe the effect of distortions on the optimal input demand by the representative intermediate good producing firm while taking both credit costs and the composition of the borrowing portfolio as given.

Lemma 3.1 (Optimal Input Choice). *Given a vector of prices (\mathbf{p}), interest rates ($\mathbf{r}^B, \mathbf{r}^T$), credit links (Θ), and the wage rate (w), firm k 's optimal demand for intermediate input s (x_{ks}) and labor (ℓ_k^Q) is*

$$p_s = \omega_{ks}^X (1 - \eta_k) \chi_k \frac{\phi_k^R}{\phi_{ks}^X} \frac{p_k q_k}{x_{ks}} \quad (3.15) \quad w = (1 - \alpha_k) \eta_k \chi_k \frac{\phi_k^R}{\phi_k^L} \frac{p_k q_k}{\ell_k^Q} \quad (3.16)$$

where the credit wedges are given by

$$\phi_k^L = 1 + r_k^B \quad (3.17) \quad \phi_{ks}^X = 1 + (1 - \theta_{ks}) r_k^B + \theta_{ks} r_s^T \quad (3.18)$$

and the revenue wedge is $\phi_k^R = 1 + r_k^T \theta_k^C$.

Proof. Provided in Appendix C.3.2. □

Due to the Cobb-Douglas production technology, expenditures on any production input are proportional to sector k 's revenues. However, as evident from Equation (3.15) and (3.16) in Lemma 3.1, the requirement to finance total input expenditures prior to the realization of any sales introduces a credit wedge between the firm's marginal cost and marginal revenue of the respective input, thereby distorting the first order conditions. While labor expenditures are exclusively financed via bank credit, firm k finances its expenditures on intermediate inputs obtained from supplier s using both bank and supplier credit. The resulting credit wedge is a weighted average of both credit costs and the weights are equal to the trade credit share. In addition, Lemma 3.1 also highlights that an increase in trade credit extended to customers ceteris paribus increases sector k 's revenues due to an increase in the effective price charged ($\phi_k^R p_k$) and thus also increases sector k 's demand for production inputs.

Corollary 3.1 (Marginal Costs of Production). *Given credit links (Θ), the marginal cost of production, p_k^V , can be decomposed into a combined credit wedge, ϕ_k^V , and a composite*

of the wage rate and the intermediate input prices and is given by

$$p_k^V = \phi_k^V mc_k^V = \left(\phi_k^L \right)^{v_k} \left(\prod_{s=1}^M (\phi_{ks}^X)^{\omega_{ks}^X} \right)^{(1-v_k)} \left(w \right)^{v_k} \left(\prod_{s=1}^M (p_s)^{\omega_{ks}^X} \right)^{(1-v_k)}. \quad (3.19)$$

The combined sectoral credit wedge $\phi_k^V > 1$ is a Cobb-Douglas composite of the individual credit costs. The marginal cost of production is increasing in the cost of bank, r_k^B , and supplier credit, r_k^T , and increasing (decreasing) in the trade credit share taken from supplier s , θ_{ks} if $r_k^B < (>) r_k^T$.

Proof. Provided in Appendix C.3.2. \square

Credit costs associated with the working capital constraint thus aggregate to a marginal cost wedge, ϕ_k^V , as shown in Corollary 3.1 and increase both, the total cost of production and the optimal goods price charged as shown in Lemma 3.2. However, if a firm also extends trade credit to its customers, the marginal revenue generated by an additional unit sold, ϕ_k^R , increases and the optimal price charged on the actual good decreases.

Lemma 3.2 (Optimal Price). *The optimal goods price equals a mark-up over marginal costs*

$$p_k = \frac{MC_k^V}{MP_k^V} = \frac{\phi_k^V}{\phi_k^R} \frac{mc_k^V}{(1 - \alpha_k \eta_k) \chi_k q_k V_k^{-1}} \quad (3.20)$$

and is increasing the composite credit wedge, ϕ_k^V and decreasing in the revenue wedge, ϕ_k^R .

Proof. Provided in Appendix C.3.2. \square

The optimality conditions were derived while taking both interest rates as well as trade credit shares as given. Therefore, I now describe the profit-maximizing supplier credit share and the optimal interest rate charged on trade credit while taking both prices and demand for trade credit as given.

Lemma 3.3 (Optimal Demand for TC). *Firm k chooses $\{\theta_{ks}\}_{s=1}^M$ to maximise profits. For $\{\theta_{ks}\}_{s=1}^M \in (0, 1)$, the FOC associated with θ_{ks} is*

$$\frac{\partial \pi_k}{\partial \theta_{ks}} : 0 = -\frac{\partial p_k^V}{\partial \theta_{ks}} V_k - (1 + r_k^B) \frac{\partial w \ell_k^T}{\partial \theta_{ks}} \quad \forall s \quad (3.21)$$

and implies that the optimal demand for trade credit is

$$\theta_{ks} = \bar{\theta}_{ks}^\kappa + \frac{(\bar{\theta}_k^S)^2}{\kappa_{1,ks}^T} \frac{\Delta_{ks} p_s x_{ks}}{1 + r_k^B} \quad \text{where} \quad \bar{\theta}_{ks}^\kappa = \left(1 - \frac{\kappa_{0,ks}^T}{\kappa_{1,ks}^T} \bar{\theta}_k^S \right) \bar{\theta}_k^S. \quad (3.22)$$

Given intermediate expenditures, $p_s x_{ks}$, and interest rates, r_s^T and r_k^B , the optimal trade credit share is decreasing in the linear cost parameter $\kappa_{0,ks}^T$ and decreasing (increasing) in the quadratic cost parameter $\kappa_{1,ks}^T$, if $\Delta_{ks} > (<) 0$. Similarly, given intermediate expenditures, $p_s x_{ks}$, the optimal trade credit share is decreasing in the interest rate charged on trade credit, r_s^T , and increasing in the interest rate on bank credit, r_k^B .

Proof. Provided in Appendix C.3.3. □

In other words, firm k chooses $\{\theta_{ks}\}_s$ such that the combined change in the cost of production and managing credit lines associated with changing the share of trade credit obtained from k 's supplier is zero at the optimum. However, it should be noted that the sign of the interest-rate differential governs the trade-off that a firm faces when choosing the composition of its credit portfolio. In particular, if the interest differential $\Delta_{ks} = r_k^B - r_s^T$ is positive such that the interest rate on trade credit offered by supplier s is cheaper than the interest rate on bank credit, then an increase in the trade credit share obtained from supplier s reduces the marginal cost of production but increases the credit management costs since $\kappa_{1,ks}^T > 0$. If the interest differential $\Delta_{ks} = r_k^B - r_s^T$ is negative, then an increase in the trade credit share obtained from supplier s increases total cost of production such that firm k chooses the trade credit share to minimize total costs.

Lemma 3.3 further highlights that the optimal trade credit share obtained from supplier s as determined by the first order condition (3.21) exhibits the following properties. It holds that, ceteris paribus, an increase in the interest rate on bank credit increases both the marginal cost of production and non-productive labor costs including interest payments of sector k , increasing the optimal share of purchases obtained on credit from sector s . On the other hand, an increase in the interest rate on trade credit decreases the optimal trade credit share for given intermediate expenditures, $p_s x_{ks}$. Given credit costs, an increase in expenditures on output of supplier s , $p_s x_{ks}$, will either increase or decrease the optimal share of inputs obtained on trade credit depending on the sign of the interest differential Δ_{ks} . Similarly, while an increase in the linear cost parameter, $\kappa_{0,ks}^T$, unambiguously increases sector k 's cost of non-productive labor and thus decreases the optimal trade credit share, the effect of an increase in the quadratic cost parameter, $\kappa_{1,ks}^T$, governing the flexibility of firms in adjusting their credit portfolio is ambiguous. The latter is due to the fact that the effect of changes in the trade credit share on marginal cost of production depends on the relative cost of credit.

The question remains: What is the optimal interest rate charged for extending trade credit to firm k 's customers? As discussed at the beginning of this chapter, firms operate under perfect competition and therefore take the demand for trade credit as given. However, the firm faces the following trade off: On the one hand, an increase in the demand for trade credit by its customers increases its revenues due to an increase in the interest

income from lending to its customers. On the other hand, the firm internalises that it also increases k 's interest rate on bank credit due to Assumption 3.3 and therefore total marginal costs of production. While taking demand for trade credit as given, firm k chooses the optimal share of total revenues extended on trade credit. This implies that the profit maximizing interest rate on trade credit, r_k^T , equalizes the marginal revenue and the marginal cost of extending trade credit to customers.

Lemma 3.4 (Optimal Interest Rate on Trade Credit). *The optimal interest rate on trade credit extended by sector k solves*

$$\frac{\partial \pi_k}{\partial \theta_k^C} : \frac{\partial \phi_k^R}{\partial \theta_k^C} p_k q_k = \frac{\partial p_k^V}{\partial \theta_k^C} V_k + \frac{\partial r_k^B}{\partial \theta_k^C} w \ell_k^T \quad (3.23)$$

and is given by

$$r_k^T = \frac{\mu r_k^Z}{\bar{\theta}_k^Z} \frac{BC_k}{p_k q_k} \quad (3.24)$$

where $BC_k = w \ell_k + \sum_{s=1}^M (1 - \theta_{ks}) p_s x_{ks}$ denotes total bank loans obtained in equilibrium. For a given share of bank loans in total revenues net of interest income from financial intermediation, the interest rate on trade credit is increasing in the responsiveness of the bank interest rate to the share of sales extended on supplier credit, μ , for $\theta_k^Z > \bar{\theta}_k^Z$ and increasing in the trade credit share extended to customers, θ_k^C .

Proof. Provided in Appendix C.3.3. □

Note that firm k sets a *common* contract rather than a link-specific contract. This implies, if customer c of firm k increases its trade credit share such that - all equal - θ_k^C increases, the interest charged on trade credit by firm k to all customers rises. In other words, the existence of common suppliers may lead to interest rate shocks spilling over from one customer of supplier s to another via an increase in the interest rate of trade credit. A common contract is assumed for simplicity - this should capture that it is costly to maintain link-specific contracts. Even if, an increase in the borrowing of one customer might affect the ability of firm k to lend to others as suggested in prior empirical work by Jacobson and von Schedvin (2015) or Costello (2017) such that the introduction of spill-overs via a common contract may be justified.

Appendix C.5 provides a summary of all equilibrium conditions of the model. At this point, it should be noted that this economy does not feature any pecuniary externalities. In other words, an efficiency constrained social planner subject to the same working capital constraints in each sector will choose the same allocations as agents in the decentralised equilibrium. While customers do not internalize the effect of their portfolio choice on the

cost of bank credit of their supplier, supplier will adjust the interest rate on trade credit charged accordingly.

Partial Equilibrium. I now elaborate on how the existence of working capital requirements distorts the economy by characterizing the partial equilibrium of the economy. I first make the following two assumptions: (1) The nominal wage rate is taken as the numeraire; and (2) Capital is at its steady state level and investment is equal to zero in equilibrium. The derivations largely follow BL(2017) with an important difference: credit wedges are also functions of the interest rates and the share of input expenditures obtained on trade credit which are both determined in equilibrium. The equilibrium collapses to that presented in BL(2017), if there are no trade credit linkages ($\theta_{ks} = 0 \forall k, s$) and firms do not require the non-productive labor input ($\ell_k^T = 0 \forall k$). Although both the cost of credit as well as the credit portfolio are interdependent and endogenous in the model, the model only admits an analytical solution of its partial equilibrium when taking interest rates as well as trade credit linkages as given. Consequently, there exists almost a one-to-one mapping of the partial equilibrium in this section to the general equilibrium analysis presented in BL(2017) as shown below. For a detailed partial equilibrium analysis, I refer to Appendix D and the discussion in BL(2017). To summarize, as shown in BL(2017), the distortions manifest themselves as an aggregate efficiency and labor wedge:

Lemma 3.5 (PE-Aggregate Efficiency and Labor Wedge). *Given interest rates on credit (\mathbf{r}) and credit linkages (Θ), an economy consisting of individual sectors operating with Cobb-Douglas production technologies and engaging in intersectoral trade aggregates to a Cobb-Douglas aggregate production function characterized by decreasing returns to scale*

$$Y = Z_z \Phi_\phi^Z L^{(1-\lambda)} \quad (3.25)$$

where Z_z denotes aggregate productivity and Φ_ϕ^Z represents the aggregate efficiency wedge which is a non-linear combination of all sectoral distortions. The aggregate labor wedge, Φ_ϕ^L , is given by

$$-\frac{L^{\epsilon_L}}{C^{1-\epsilon_C}} = \Phi_\phi^L (1-\lambda) \frac{Y}{L} \quad (3.26)$$

and is defined as a wedge between the household's marginal rate of substitution between consumption and labor and the aggregate marginal product of labor.

Proof. Proofs are provided in Appendix D. (see also Bigio and La'O, 2017, for a comparison) \square

As evident from Equation (3.25) and (3.26), the presence of distortions - in this thesis working capital constraints - leads to a misallocation of resources and an efficiency loss. However, Equations (3.25) and (3.26) mask that the aggregate wedges are in fact not only a function of the interest rates on bank and trade credit, but also a function of the credit network, Θ , which in equilibrium is the outcome of firms minimizing their total cost of production. Since firms are both lenders and borrowers of trade credit at the same time, clearly, this implies that distortions in this economy are interlinked which affects the propagation of liquidity shocks in this economy. I now discuss the role of endogenous credit links for the propagation of liquidity shocks in the next section.

3.2 Propagation of Financial Shocks

It has been shown that - as common to models with distortions (i.a. [Bigio and La'O, 2017](#); [Baqee and Farhi, 2018, 2019](#)) - working capital constraints introduce an aggregate efficiency and labor wedge, thereby generating an efficiency loss as resources are diverted from being used for production. However, due to the nature of trade credit, distortions in this model are not only endogenous but also interdependent. In particular, as firms adjust both their lending rates and their borrowing portfolio, credit cost of production and credit linkages are subject to changes along the intensive margin and consequently distort the transmission of shocks.

This section discusses the role of endogenous credit links on the propagation of financial shocks. In Section 3.2.1, I highlight that trade credit can both dampen and amplify the output response of sectors following an idiosyncratic liquidity shock. The first round response of a representative firm in sector k to an increase in its cost of bank credit illustrates how a financial shock propagates both up- and downstream, generating counteracting output responses: On the one hand, firm k will shift its borrowing portfolio towards trade credit which reduces the output effect of the cost shock. On the other hand, both the price of the good as well as the interest rate charged on trade credit increase, subsequently exacerbating the reduction in the demand for k 's output.

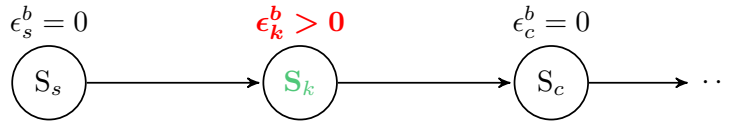
In Section 3.2.2, I discuss the equilibrium response of output by elaborating on the determinants of its elasticity with respect to shocks to the cost of bank credit. For this purpose, I log-linearize the model around its steady state as shown in Appendix E. This allows a decomposition of the log-change of all variables of interest into changes attributed to (1) productivity shocks, (2) general equilibrium adjustments in the aggregate labor supply and (3) changes in distortions introduced as credit wedges. The credit wedges summarize the composite effect of changes in credit costs and the composition of the credit portfolio on sectoral sales, prices and output. Since distortions in this model are

interdependent, I also define the credit multiplier summarizing the total effect of shocks to the bank risk premium on interest rates and the credit portfolio. It is shown that, to a first order approximation, the structural elasticities are functions of equilibrium expenditures, accounts payable and receivables, which determines the strength of the trade credit channel introduced in Section 3.2.1 on output.

3.2.1 Trade Credit Mechanism

In order to develop some intuition on how changes in credit costs propagate both up- and downstream, I consider the following demand structure between sector k , its customer c and its supplier s as depicted in Figure 3.3a: (1) sector k does not supply output to itself ($\omega_{kk}^X = 0$), (2) the flow of goods between a pair of sectors is directed such that each sector clearly identifies as either the customer or the supplier ($\omega_{sk}^X = \omega_{kc}^X = 0$) and (3) none of the sectors' output is used in the production of the final good ($\omega_s^F = \omega_k^F = \omega_c^F = 0$).

Figure 3.3a: Production Supply Chain - Line Subgraph



Note: This figure depicts the demand structure between sector k , supplier s and customer c and a shock to the bank risk premium of sector k , $\epsilon_k^b > 0$, only. Productivity remains at its equilibrium level such that $\epsilon_i^q = 0$ for $i \in \{s, k, c\}$.

Using standard graph theoretical notation (see e.g. [Carvalho, 2010](#)), I will refer to this subgraph of the production network defined by the intermediate and final demand input-output matrices, $\Omega = \{\Omega^X, \Omega^F\}$, as the line-subgraph, $G_L(\Omega)$:

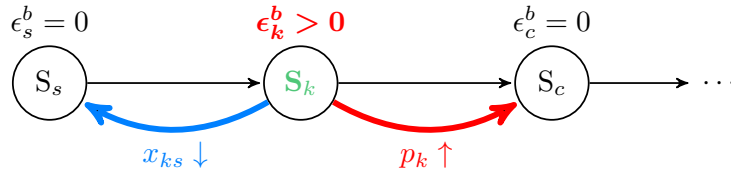
Definition 3.2 (Line-Subgraph). *Let $G(\Omega) = G(\mathcal{V}, \mathcal{E})$ be a directed sectoral trade linkages graph, where \mathcal{V} is the vertex set of $(M + 1)$ intermediate and final good producing sectors labelled $\{v_0, v_1, \dots, v_M\}$ and \mathcal{E} is set of all ordered pairs of vertices $\{v_i, v_j\}$ for which $\omega_{ij} > 0$ holds. Define the line-subgraph as $G_L(\mathcal{V}_L, \mathcal{E}_L) \subset G(\mathcal{V}, \mathcal{E})$, where $\mathcal{V}_L = \{v_s, v_k, v_c\}$ and $\mathcal{E}_L = \{\{v_s, v_k\}, \{v_k, v_c\}\}$.*

Let the demand structure be given by $G_L(\Omega)$. Consider now a financial shock to the bank risk premium of the representative firm in sector k , $z_k^b = \epsilon_k^b > 0$, such that k 's interest rate on bank credit defined in Equation (3.8) increases. Using the results of the previous section, Corollary 3.2 to 3.4 elaborate on the direct propagation of an idiosyncratic shock to the bank risk premium of the representative firm in sector k , r_k^Z , to its customer c and supplier s , while abstracting from any feedback and general equilibrium effects. The respective proofs are provided in Appendix C.4.

Corollary 3.2 (Effects of Changes in k 's Interest Rate on Bank Credit). *An increase in sector k 's interest rate on bank credit, r_k^B , increases k 's marginal cost of production. Sector k 's demand for inputs and therefore supplier s 's output decrease. Sector k 's price charged for k 's output and therefore customer c 's marginal cost of production increase, decreasing c 's demand for inputs. Sector k 's output decreases.*

Corollary 3.2 describes how an increase in sector k 's interest rate on bank credit, r_k^B , affects sector k 's cost of production and translates into demand effects upstream and cost effects downstream as depicted graphically in Figure 3.3b. Output in all three sectors declines.

Figure 3.3b: Effects of Changes in the Cost of Bank Credit



Note: This figure illustrates the demand and price effects of an increase in sector k 's interest rate on bank credit following a shock to k 's risk premium, $\epsilon_k^b > 0$, along the supply chain formed by sector k , supplier s and customer c . Productivity remains at its equilibrium level such that $\epsilon_i^q = 0$ for $i \in \{s, k, c\}$.

It should be noted, that a shock to the interest rate on bank credit exhibits the same propagation pattern as an increase in exogenous sectoral distortions in the model economy introduced in BL(2017) or a negative productivity shock to sector k . However, the existence of trade credit introduces additional propagation channels via changes in both the cost of trade credit and trade credit shares, as will be discussed in the following paragraphs. Corollary 3.3 summarizes the effect of an increase in sector k 's bank risk premium on k 's interest rate charged on trade credit.

Corollary 3.3 (Effects of Changes in k 's Interest Rate on Trade Credit). *The increase in sector k 's bank risk premium, r_k^Z , - ceteris paribus - increases k 's interest rate charged on trade credit, r_k^T , and customer c 's marginal cost of production. Sector c 's demand for inputs and thus sector k 's output decrease.*

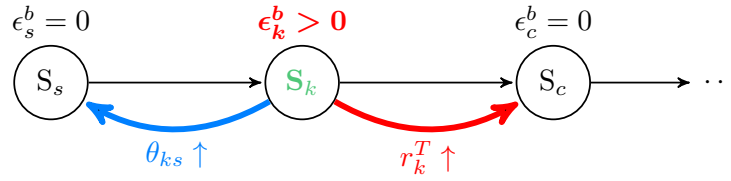
Using the results of Lemma 3.4, Corollary 3.3 describes how a shock to sector k 's bank risk premium, r_k^Z , translates into cost effects downstream, operating in addition to the traditional cost effect via prices described in Corollary 3.2. In other words, while abstracting from any general equilibrium effects, an increase in sector k 's interest rate on trade credit increases customer c 's production costs beyond the initial increase induced by a rise in the price of k 's output. Therefore, sector c decreases its demand for k 's output even further. Note that changes in k 's interest rate on trade credit have no immediate income and cost effects affecting supplier s 's sales, prices and output. Similarly,

by applying the results of Lemma 3.3 and abstracting from general equilibrium effects, Corollary 3.4 describes the effect of changes in the credit composition of sector k .

Corollary 3.4 (Effects of Changes in k 's Trade Credit Share). *An increase in sector k 's interest rate on bank credit, r_k^B - ceteris paribus - increases sector k 's share of inputs obtained on trade credit from supplier s and consequently dampens k 's initial increase in marginal cost of production and decrease in output induced by the shock to k 's cost of bank credit.*

Corollary 3.3 and 3.4 summarize how the direct response of trade credit costs and shares of the affected sector distorts the up- and downstream transmission of a shock to its interest rate on bank credit, as depicted in Figure 3.3c: On the one hand, as firms also increase the interest rate charged on trade credit, the cost shock to their customers is amplified beyond the traditional price channel. On the other hand, the ability of firms to substitute bank and supplier credit implies that the own cost effect and therefore upstream demand effect of an increase in bank financing costs is dampened.

Figure 3.3c: Trade Credit Channel



Note: This figure illustrates the trade credit channel for a shock to sector k 's risk premium, $\epsilon_k^b > 0$, along the supply chain formed by sector k , supplier s and customer c . Productivity remains at its equilibrium level such that $\epsilon_i^q = 0$ for $i \in \{s, k, c\}$.

Based on the previous discussion of the direct effects of changes in the cost of credit and the input-specific borrowing portfolio, I now define the Trade Credit Channel as follows

Definition 3.3 (Trade Credit Channel). *Consider an economy with working capital constraints and two sources of external funds: bank and trade credit. Let the optimal interest rate on trade credit and the optimal credit share be defined in Lemma 3.4 and 3.3, respectively. The ability of firms to delay input payments to their suppliers introduces two opposing channels via which trade credit affects economic outcomes:*

- (a) *(Amplification) An increase in the cost of bank finance of a firm directly translates into an increase in interest rate charged on trade credit, thereby tightening the financing terms for its customers.*
- (b) *(Smoothing) The existence of two external financing sources allows firms to smooth any interest rate shocks via an adjustment of their borrowing portfolio by optimally trading-off credit costs.*

In foresight of the quantitative application of the model, two observations are worth mentioning: First, the strength of the amplification channel will be influenced by the elasticity of the bank risk premium with respect to the share of revenues extended on trade credit, μ . This follows from the optimal interest rate charged on trade credit derived in Lemma 3.4, which increases in the parameter μ for $\theta_k^Z > \underline{\theta}_k^Z$. Second, the extend to which firms are able to smooth credit shocks will depend on two conditions: (1) the parameter governing the convexity of the credit management cost function, $\kappa_{1,ks}^T$, defined in Equation (3.7) and (2) the type of shocks present in this economy. The first condition implies that a lower cost parameter increases the ability of firms to substitute credit sources and thus increases the smoothing channel in this economy. The second circumstance relates to the fact that, in the case of an aggregate shock, firm k 's supplier s of trade credit and consequently s 's interest rate charged on trade credit will also be directly affected by the shock. Ultimately, the question of which effect dominates remains an quantitative question and will be investigated in Chapter 4.

3.2.2 Equilibrium Effect on Output

While the previous section provided an insight into the up- and downstream propagation channels introduced by trade credit, this section elaborates on the determinants of the elasticity of output with respect to financial shocks. For this purpose, I first discuss the (partial) equilibrium effects at work by log-linearizing the model around its steady state⁴. The log-linearized equilibrium highlights, how the response of sales, prices and output can be attributed to changes in the cost of credit and the credit portfolio. In the second part of this section, I discuss the interdependency of credit costs and the implications thereof for the response of output. For the remainder of the discussion in this section, I impose the following restriction on the production parameters.⁵

Assumption 3.4. *The vector of parameters governing the degree of decreasing returns to scale in each sector, χ , is such that (1) an increase in the cost of the production function increases prices and (2) a decrease in sales decreases output.*

Assumption 3.4 takes into account that prices will be increasing in sales due to the presence of DRS: Consider an increase in the cost of production which increases prices on the one hand and reduces sales on the other. The latter effect on sales counteracts the initial price increase. Similarly, a decrease in sales decreases output but also decreases prices, which will have positive effect on output. Assumption 3.4 ensures that the counteracting effects on prices and output introduced by DRS do not outweigh the standard cost and demands effects. In the following, I now discuss the different channels through

⁴A definition of the log-linearized equilibrium is provided in Appendix E.1, Definition E.1 and E.2.

⁵A formal discussion is presented in Appendix E.1.

which distortions can affect economic outcomes. Proposition 1 characterizes the effects of changes in intermediate credit ($\hat{\phi}_m^L, \hat{\phi}_{mn}^X \forall m, n$), final demand ($\hat{\phi}_F^R$) and revenue wedges ($\hat{\phi}_m^R \forall m$) on prices, output and revenues of a representative firm in sector k .

Proposition 1 (Effects of Distortions). *In the log-linearized equilibrium, an increase in*

- (a) *sector k 's credit wedges, as well as in its direct and indirect **suppliers**' credit wedges, $\hat{\phi}_m^L, \hat{\phi}_{mn}^X \forall m, n$, increases the cost of production and prices and decreases k 's output. (Cost Effect)*
- (b) *sector k 's direct and indirect **customers**' credit wedges, $\hat{\phi}_m^L, \hat{\phi}_{mn}^X \forall m, n$, increases the cost of production and decreases the demand for k 's output. (Demand Effect)*
- (c) ***revenue wedges**, $\hat{\phi}_m^R \forall m$, from extending trade credit to customers directly and indirectly increases k 's income from financial intermediation, decreases sector k 's price, and thus increases output. (Income Effect of Financial Intermediation)*
- (d) *the **final demand wedge**, $\hat{\phi}_F^R$, reduces the profit and interest income of households and demand for the final good. Sector k 's price due to DRS, output and revenues decrease. (Income Effect of Final Demand)*

Proof. Provided in Appendix E.1. □

Proposition 1 highlights that in addition to the standard cost and demand effects of credit wedges associated with the working capital constraint, the extension of trade credit to customers also introduces an income effect from financial intermediation. As discussed in the previous sections, a sector obtains revenues from both selling its output and acting as a financial intermediary by extending trade credit to its customers. Therefore, the effective price paid by a customer of firm k is a bundle of the actual price and the interest rate charged on the share of input costs obtained on trade credit. Taking the demand for trade credit as given, an increase in the interest rate on trade credit increases k 's revenue wedge and consequently the marginal revenue of the additional unit sold on credit. As a result, the increase in the revenue wedge reduces the output price. The reduction in the price of input k increases the demand for k 's output and subsequently production and sales. However, credit and revenue wedges are interdependent and can further be decomposed into effects attributed to changes in the interest rates on bank and trade credit, and trade credit shares which affects the propagation of shocks as will be discussed in the remainder of this section.⁶

⁶Lemma E.1 to E.3 in Appendix E.2 present a formal derivation of the composition of the credit wedges affecting sales, prices and output into changes attributed to the interest rate and bank and trade credit and the composition of the credit portfolio.

Lemma 3.6 describes the first order impact of changes in credit costs and shares on revenues and credit wedges associated with financing the cost of labor and purchasing inputs from intermediate good suppliers, defined in Section 3.1.

Lemma 3.6 (Revenue and Credit Wedges). *The labor, ϕ_k^L , and the intermediate credit wedge, ϕ_{ks}^X , of sector k increase in the cost of credit, r_k^B and r_s^T . The intermediate credit wedge, ϕ_{ks}^X , increases (decreases) in the trade credit share, θ_{ks} , if the equilibrium interest rate differential ($\bar{r}_k^B - \bar{r}_s^T$) is negative (positive). The revenue wedge of sector k , ϕ_k^R , increases in the interest rate on trade credit, r_k^T , and in the trade credit share extended to customers, θ_k^C .*

Proof. Provided in Appendix E.2. □

Combining the results of Lemma 3.6 and Proposition 1, it becomes apparent that the existence of trade credit and resulting interdependency of distortions introduce counteracting cost and income effects affecting the propagation of shocks to customers and suppliers. In order to shed more light on the equilibrium effects generated by inter-firm credit linkages in response to a financial shock, the following paragraphs discuss the different channels through which changes in the interest rate on bank and trade credit and trade credit shares affect sales, prices and output.⁷

First, note that in general, the effect of an increase in the share of input payments obtained on trade credit on the cost of production and subsequently prices, output and sales depends on the interest rate differential and is ambiguous. Following Proposition 1, intermediate *revenues* are affected by changes in the credit costs of customers, the income from financial intermediation and household's income: An increase in customer c 's interest rate on bank credit as well as in sector k 's interest rate charged on trade credit, increases c 's cost of production. Consequently, the demand for k 's output and thus sales decline. At the same time, an increase in sector k 's trade credit rate or share of sales extended on trade credit increases k 's interest income from financial intermediation and thus sales as discussed above. Changes in the interest and profit income of households due to changes in credit costs and shares are captured by the final demand wedge. On the one hand, an increase in c 's bank rate increases the interest income of households and subsequently intermediate sales. On the other hand, an increase in either sector k 's interest rate charged on trade credit or trade credit share obtained by sector c lowers the profit income of households, and ultimately both final and intermediate sales.

Changes in sectoral *prices* induced by changes in credit costs and shares are the result

⁷For illustrative purposes, I abstract from productivity shocks and consider the partial equilibrium case only, assuming that both productivity and aggregate labor remain at their equilibrium levels. In addition, I further simplify the discussion by abstracting from any feedback effects from changes in the composition of sales.

of two channels: (1) the cost- and (2) the demand channel. The latter feedback effect via changes in sales is present due to DRS and according to Assumption 3.4 either reinforces or dampens the cost channel, discussed in the following: An increase in the cost of credit of sector k and k 's direct and indirect suppliers increases the cost of production and therefore the price charged on output of sector k . However, an increase in the interest rate charged on trade credit as well as an increase in the customers' share of inputs payments obtained on trade credit increases k 's marginal revenues from selling its output on credit. The resulting decrease in prices counteracts the cost effect. The response of *output* is the result of the combined effect of distortions on the cost of production and demand. To the extent that the cost effects described above dominates any counteracting income effects from financial intermediation and households, output decreases. Overall, the previous discussion highlights that in general, the total effect of changes in the cost of trade credit and the credit portfolio on economic outcomes is ambiguous and depends on the demand and supply structure of the economy.

As evident from the Lemma 3.4 and 3.3 in Section 3.1, credit costs and the composition of the input-specific credit portfolio are interdependent such that there exists a credit multiplier that captures the total effect - direct and indirect - of changes in credit conditions on the variables of interest in addition to the feedback effects operating via the production structure. The credit multiplier of the economy is defined as follows.

Definition 3.4 (PE-Credit Multiplier). *In partial equilibrium assume that $\widehat{L} = 0$ and abstract from any feedback effect of changes in the composition of sales on the average trade credit share extended to customers, $\widehat{w}_{ck}^X = 0 \forall c, k$ where $w_{ck}^X = x_{ck}(q_k)^{-1}$. The vector of changes in credit costs and shares, $\boldsymbol{\tau} = [\widehat{\boldsymbol{r}}^B, \widehat{\boldsymbol{r}}^T, \widehat{\boldsymbol{\theta}}]$, is given by*

$$\boldsymbol{\tau} = \boldsymbol{E}_\tau^\tau \boldsymbol{\tau} + \boldsymbol{E}_\tau^{Z_b} \boldsymbol{\epsilon}_b \quad (3.27)$$

where the elasticity matrices \boldsymbol{E}_τ^τ and $\boldsymbol{E}_\tau^{Z_b}$ summarize the equilibrium-network effects via prices and sales on the respective variables of interest and are defined in Lemma E.4 and E.5. The credit multiplier and its first order approximation are then given by

$$\boldsymbol{\Psi}_\tau = (\boldsymbol{I} - \boldsymbol{E}_\tau^\tau)^{-1} \approx \widetilde{\boldsymbol{\Psi}}_\tau = \boldsymbol{I} + \boldsymbol{E}_\tau^\tau. \quad (3.28)$$

The log-linearization of interest rates and the portfolio choice derived in Lemma 3.4 and 3.3 and applying Definition 3.4 yields the first order approximation of the partial equilibrium responses of credit costs and shares.

Proposition 2 (PE-Structural Credit Responses). *Let the first order approximation of the PE-credit multiplier, Ψ_τ , be defined in 3.4. The partial equilibrium structural responses of r_k^B , r_k^T and θ_{ks} are*

$$\tilde{r}^B = +\mathbf{E}_B^{Z_b} \epsilon_b, \quad \tilde{r}^T = [-\mathbf{E}_T^B \mathbf{E}_B^{Z_b} + (\mathbf{I} + \mathbf{E}_T^T) \mathbf{E}_T^{Z_b}] \epsilon_b \quad \text{and} \quad \tilde{\theta} = [+ \mathbf{E}_\theta^B \mathbf{E}_B^{Z_b} - \mathbf{E}_\theta^T \mathbf{E}_T^{Z_b}] \epsilon_b \quad (3.29)$$

in the absence of productivity shocks, $\epsilon_k^q = 0 \forall k$. The elasticity matrices \mathbf{E}_B^v , \mathbf{E}_T^v and \mathbf{E}_θ^v for $v \in \{Z_b, B, T, \theta\}$ denote the elasticities of the interest rate on bank and trade credit and trade credit shares with respect to one-another and are derived in Lemma E.4 and E.5 in Appendix E.4.

Proof. Provided in Appendix E.4. □

It follows that sector k 's *interest rate on bank credit* is increasing in shocks to the sector-specific risk premium and in the trade credit shares extended to customers. The response of the *interest rate on trade credit* charged by sector k depends on (a) the elasticity of k 's interest rate on bank credit with respect to shocks to the risk premium and (b) the response of the share of bank loans in revenues, as evident from Equation (3.24) and discussed in the following. An exogenous increase in the risk premium charged on bank credit increases marginal costs of bank borrowing from extending trade credit to customers. Similarly, an increase in the share of sales extended on trade credit to customers also increases sector k 's cost of bank credit due to Assumption 3.3. In either case, sector k 's interest rate charged on trade credit unambiguously increases. Simultaneously, the response of the interest rate on trade credit will also be affected by changes in the share of bank loans in revenues. From the previous discussion, an increase in the cost of production decreases k 's demand for inputs and subsequently total bank credit obtained by k . Intuitively, the interest rate charged on trade credit decreases as k 's dependency on bank loans and therefore its exposure to the financial shock has decreased.

Sector k 's profit maximizing *share of inputs obtained on trade credit* from supplier s is defined in Equation (3.22). It follows that the response of k 's credit portfolio to changes in credit costs and shares depends on the relative change in the interest rates as well as on the change in total intermediate expenditures on inputs from sector s following a financial shock. While the elasticity of sector k 's share of inputs obtained on trade credit from supplier s with respect to changes in input expenditures is ambiguous and depends on the interest rate differential as discussed above, the interpretation regarding the direct effect of changes in credit costs is more intuitive. Given intermediate expenditures, an increase in the interest rate on bank credit unambiguously induces a shift of the credit portfolio towards trade credit from supplier s . Similarly, an increase in the interest rate charged on trade credit by supplier s unambiguously decreases the trade credit share.

Therefore, the equilibrium adjustment of the credit portfolio will depend on the relative response of the cost of bank and trade credit. If the interest rate on trade credit displays a higher increase than the interest rate on bank credit in response to a shock to the bank risk premium, firms may still shift their credit portfolio towards bank credit. This pattern has been observed in the data at the onset of the crisis as discussed in Chapter 2 and suggests that the cost of trade credit may be more volatile than the interest rate on bank credit.

The previous discussion highlights that the existence of trade credit linkages implies that shocks to the cost of bank credit are passed on through the input-output network both up- and downstream by affecting the cost of credit and portfolio choices. By combining the first order approximation of the credit multiplier defined in 3.4 as well as the log-linearized equilibrium derived in Appendix E.1, I am now able to provide a characterization of the partial equilibrium structural output response while taking into account the interdependencies of trade credit costs and shares.

Proposition 3 (PE-Structural Output Response). *Consider the partial equilibrium in Definition 3.4 and let the response of the interest rate on bank and trade credit and trade credit shares be given in Equation (3.29) in the absence of productivity shocks, $\epsilon_k^q = 0$.*

(a) *The first order approximation of the structural output response to shocks to the cost of bank credit, ϵ_m^b , is*

$$\tilde{q}_k = - \sum_{m=1}^M [\tilde{\mathbf{S}}_B^Q]_{km} \epsilon_m^b = - \sum_{m=1}^M \left\{ [\tilde{\mathbf{S}}_{B,B}^Q]_{km} + [\tilde{\mathbf{S}}_{B,T}^Q]_{km} \right\} \epsilon_m^b \quad (3.30)$$

and represents the total effect of changes in the cost of bank credit ($\tilde{\mathbf{S}}_{B,B}^Q$) and of changes in the interest rate on trade credit and trade credit shares ($\tilde{\mathbf{S}}_{B,T}^Q$) on output.

(b) *The components of the partial equilibrium structural elasticity of output wrt a financial shock to sector m , ϵ_m^b ,*

$$[\tilde{\mathbf{S}}_{B,B}^Q]_{km} = +\bar{r}_m^B [\mathbf{E}_B^{Z_b}]_{mm} \left\{ [\mathbf{S}_{Q,B}^{B(L)}]_{km} \bar{w}_m^Q + \sum_{s=1}^M [\mathbf{S}_{Q,B}^{B(X)}]_{k,ms} \bar{A} \bar{P}_{ms}^- \right\} \quad (3.31)$$

$$\begin{aligned} [\tilde{\mathbf{S}}_{B,T}^Q]_{km} = & -\bar{r}_m^B [\mathbf{E}_B^{Z_b}]_{mm} \left\{ [\mathbf{S}_{Q,T}^{B(L)}]_{km} \bar{w}_m^Q + [\mathbf{S}_{Q,T}^{B(\theta)}]_{km} \bar{w}_m^T + \sum_{s=1}^M [\mathbf{S}_{Q,T}^{B(X)}]_{k,ms} \bar{A} \bar{P}_{ms}^- \right\} \\ & + \bar{r}_m^T [\mathbf{E}_T^{Z_b}]_{mm} \sum_{c=1}^M \left([\mathbf{S}_{Q,T}^{T(X)}]_{k,cm} + [\mathbf{S}_{Q,T}^{T(\theta)}]_{k,cm} \right) \bar{A} \bar{R}_{cm} \end{aligned} \quad (3.32)$$

are a linear combination of sector m 's production costs that need to be financed at the beginning of the period ($\bar{w}_m, \bar{A} \bar{P}_{ms}^-$) and accounts receivable ($\bar{A} \bar{R}_{cm}$), where $\bar{A} \bar{P}_{ms}^- = (1 - \bar{\theta}_{ms}) \bar{p}_s \bar{x}_{ms}$. The structural elasticity matrices $\{\mathbf{S}_{Q,B}^{B(v)}, \mathbf{S}_{Q,T}^{B(v)}, \mathbf{S}_{Q,T}^{T(v)}\}$ for $v \in \{L, X, \theta\}$,

are given in (E.31) and are functions of the elasticity of the output response wrt changes in the interest rate on bank and trade credit, and the trade credit share, defined in Lemma E.3, E.4 and E.5.

Proof. Provided in Appendix E.5. □

The first part of Proposition 3 illustrates that the partial equilibrium sectoral output response is ultimately a function of the structural output wedge. The elasticity thereof with respect to shocks to the bank risk premium can be decomposed into an elasticity attributed to changes in the interest rate on bank credit ($\tilde{\mathbf{S}}_{B,B}^Q$), and to changes in the credit composition and the interest rate on trade credit ($\tilde{\mathbf{S}}_{B,T}^Q$). In the second part of the proposition, Equations (3.31) and (3.32) derive that the elasticity of sector k 's output response is a function of: (a) k 's elasticities of output with respect to credit costs and shares and (b) m 's production costs that need to be financed using bank loans as well as m 's accounts receivable. In particular, the latter captures sector m 's partial equilibrium structural elasticities of the interest rate on bank credit, sector m 's interest rate charged on trade credit and of the credit portfolio with respect to financial shocks.

To summarize, Proposition 3 highlights that the relationship between a sector's equilibrium total up-front financing needs and trade credit extended determines the elasticities of the variables of interest with respect to financial shocks. Therefore, I define the net-lending position of a sector as the ratio of total trade credit extended to customers (accounts receivable) to the difference between total cost of production and accounts payable (see Definition 2.1). I conclude this section by elaborating on how the dependency of an economy on trade credit can affect the response of output following a financial shock. In particular, I pose the question: How does a sector's net-lending position affect the elasticity of sectoral output with respect to changes in the interest rate on trade credit and the credit composition?

Proposition 4. *Let the partial equilibrium elasticity of output with respect to shocks to the cost of bank credit, ϵ_m^b , be defined in Proposition 3. Let sector m be a net-borrower (net-lender) in the economy such that $[\tilde{\mathbf{S}}_{B,T}^Q]_{km} < (>) 0$ holds. Then, the adjustment of trade credit costs and credit shares will smooth (amplify) the negative effect of an increase in the interest rate on bank credit affecting sector m on (partial equilibrium) output of sector k .*

Proof. Provided in Appendix E.5. □

In other words, if a sector is affected by a financial shock whose (weighted) upfront total financing costs are larger (smaller) than the (weighted) trade credit extended to customers - the sector classifies as a net-borrower (net-lender) according to Definition 2.1

- then trade credit has a smoothing (amplifying) effect. Based on the discussion above, the intuition thereof is as follows: A sector k 's interest rate on trade credit will be more sensitive to financial shocks, the more trade credit k extends to customers. Consequently, a financial shock will induce a stronger increase in a sector's interest rate charged on trade credit, who records higher accounts receivable. Therefore, the cost effect on output discussed above will be amplified. Similarly, a sector with a higher equilibrium dependency on bank credit will experience a stronger cost effect and therefore a greater reduction in its demand for inputs and the share of bank loans in total sales. As a result, the interest rate on trade credit declines and dampens the output response to a financial shock. In the case of trade credit shares, the effects depend on the interest rate differential. However, an increase in the dependency on bank credit may reinforce the positive effect of changes in the credit portfolio on income from financial intermediation, counteracting the increase in prices discussed above. At the same time, an increase in a sector's reliance on trade credit will amplify any cost effects induced by changes in the credit composition. As a result of Proposition 4, the following property holds

Corollary 3.5. *Let the partial equilibrium elasticity of output with respect to shocks to the cost of bank credit, ϵ_m^b , be defined in Proposition 3. Consider the output elasticity with respect to changes in the cost of trade credit and trade credit shares, $\tilde{\mathbf{S}}_{B,T}^Q$. Taking $\{\mathbf{S}_{Q,T}^{B(v)}, \mathbf{S}_{Q,T}^{T(v)}\}$ for $v \in \{L, X, \theta\}$ as given and assuming that the respective matrix entries are positive, the following property holds: the smoothing effect of the trade credit channel on output decreases if the equilibrium share of intermediate inputs obtained on trade credit by (1) sector m from supplier s and (2) customer c from sector m increases.*

Proof. Corollary 3.5 follows directly from Proposition 3. □

Corollary 3.5 implies that an increase in the dependency on trade credit by either increasing trade credit obtained from suppliers or extended to customers, increases the structural elasticity of output with respect changes in the interest rate on trade credit and the credit composition increasing a sector's cost of production.

3.3 Concluding Remarks

This chapter introduced a static quantitative multisector model with trade in intermediate inputs and endogenous trade credit linkages and costs between perfectly competitive intermediate good producing firms in each sector. Firms face working capital constraints and are therefore required to finance production using both bank and supplier credit. This implies that resources are diverted from a productive use of inputs such that the cost of financing production expenditures translate into cost-, and aggregate efficiency-

and labor-wedges, distorting the first order conditions of agents in this economy. While this result is common to any model featuring distortions, the nature of trade credit introduces an interdependency of credit costs and portfolio choices as highlighted in this chapter.

It is shown that the existence of trade credit in an economy distorts the transmission of financial shocks and has both smoothing and amplifying effects. In particular, as credit conditions tighten in an economy, the endogenous adjustment in the volume and cost of trade credit captures two counteracting mechanisms: (1) Firms smooth interest rate shocks by substituting bank and supplier finance. (2) Any increase in the interest rate that a firm charges on trade credit tightens the financing terms of its customers thereby amplifying financial shocks. Furthermore, it is shown in Proposition 4 that sectors extending a lot of trade credit to their customers relative to their own financing needs play a crucial role in the transmission of shocks to the cost of external funds. However, the question of which aspect of the trade credit channel is more operative in an economy and how it affects aggregate fluctuations ultimately needs to be answered quantitatively.

Chapter 4

A Quantitative Assessment of Trade Credit and Aggregate Fluctuations

In this chapter, I apply the framework introduced in Chapter 3 to the US economy to quantitatively evaluate the effects of trade credit linkages on business cycle comovement, aggregate fluctuations and sectoral outcomes during the 2008-2009 financial crisis. In particular, I provide answers to the following two questions: (1) Did the interfirm credit network amplify or smooth financial shocks during the Great Recession in comparison to an economy without trade credit? (2) To what extent does the trade credit channel - the endogenous adjustment of trade credit volumes and prices - contribute to aggregate fluctuations?

To this end, I first calibrate the equilibrium of the model at a sector level in Section 4.1, using the model's first order conditions. The US production and trade credit network is mapped based on the input-output tables provided by the Bureau of Economic Analysis and based on balance sheet data on accounts receivable and payable of a panel of US firms from Compustat. Sectoral credit spreads derived in Gilchrist and Zakrajšek (2012) are used to calibrate and impute the sector-specific shocks to the risk premium of the bank interest rate in Equation (3.8). The imputed financial shocks are then used to simulate the model economy in Section 4.2, while abstracting from any shocks to sectoral productivity. A comparison of the model-implied responses of the credit portfolio of sectors and aggregate output with the fluctuation patterns presented in Chapter 2 suggests, that the model reproduces - both qualitatively and quantitatively - business cycle patterns of trade credit as observed in the data. In particular, the model captures approximately a quarter of the variation of, and one third of the drop in, aggregate output during the financial crisis. A variety of simulation exercises are then conducted in Section 4.2 in order to quantify the role of trade credit for business cycle comovement and aggregate fluctuations during the crisis. The following three main results are derived: First, the existence of trade

credit linkages almost doubled the decline in output relative to an equivalent economy with bank finance only and can account for approximately 16% of the drop in aggregate output during the 2008-2009 crisis. Second, the endogenous adjustment of the volume and cost of trade credit only reduced aggregate volatility by 1.4%, which suggests that the smoothing mechanism of trade credit was operative, though small. Third, firms which act as important financial intermediaries for their customers are systemically important and generate large spillovers, which quantifies and confirms the predictions of the model derived in Chapter 3.

4.1 Calibration Strategy

The static nature of the model and its analytical tractability allow me to conduct a period-by-period mapping of the equilibrium of the model to the empirical counterparts of the US economy at a sector level¹ using the model's first order conditions. In the following, I first discuss the calibration of the production structure as well as the trade credit network following a standard approach applied in the literature (Bigio and La'O, 2017; Altinoglu, 2018). I then obtain the time series of shocks to a sector's bank risk premium inferred from sectoral credit spreads derived in Gilchrist and Zakrajšek (2012) as discussed below. In the last paragraphs, the calibration of the cost parameters associated with the interest rate on bank credit and credit management costs are discussed in further detail. Section 4.1.2 then provides descriptive statistics of the calibrated US production and credit network obtained in Section 4.1.1. I conclude this section by discussing additional business cycle statistics of selected real and financial variables as well as characteristics of sectoral distortions in Section 4.1.3 and 4.1.4.

4.1.1 A Mapping of the US Product and Trade Credit Market

Production and Financial Network Data . The input-output tables from the Bureau of Economic Analysis (BEA) are used to map the production structure of the US economy at the 3-digit NAICS industry level at an annual frequency, covering the time period 1997-2016. In total 45 sectors (excluding FIRE) are included in the analysis. While data on the production structure of the US economy is readily available, data on trade credit flows between production units at a firm or sectoral level is not². In order to overcome these

¹Due to the paucity data at a firm level, I conduct the quantitative analysis at a sector level, which does not affect the qualitative implications of the model.

²An exception for the US is Costello (2017), who employs proprietary transaction data from Credit2B; proprietary firm-to-firm transaction data are also used in recent empirical contributions by Jacobson and von Schedvin (2015) for Sweden, Dewachter et al. (2018) for Belgium, Giannetti et al. (2018) for Italy or Cortes et al. (2018) for Brazil.

data-limitations on the inter-firm credit network, I construct a proxy of inter-industry credit flows using the approach suggested in [Altinoglu \(2018\)](#). The balance sheet data of a panel of US firms³ from Compustat are used to calculate the share of accounts payable in total input expenditures (θ_k^P) and the share of accounts receivable in total revenues (θ_s^R) at an industry level. The inter-industry trade credit share from supplier s to customer k is constructed as a (sales) weighted average of the trade credit shares

$$\theta_{ks} = \frac{R_s}{R_k + R_s} \theta_k^P + \frac{R_k}{R_k + R_s} \theta_s^R \quad (4.1)$$

and is non-zero only if both sectors also engage in trade in intermediate inputs.

The second complication in mapping the model to the data is the consistent assignment of interest rate costs on bank and trade credit for the derivation of the production function parameters. The nominal intermediate input expenditures recorded in the IO-tables are net of any interest payments on bank credit associated with the transactions. Note that any interest payments on trade credit are part of the effective price paid, and are therefore already accounted for in the nominal intermediate expenditures shown in the IO-tables. Bank interest rate expenditures, however, are recorded as part of the gross operating surplus in the IO-tables net of interest-income. (see [Horowitz and Planting, 2009](#)). I thus decompose the gross-operating surplus into capital expenditures, dividend payments and bank interest rate expenditures using the shares of the respective counterparts in gross operating profits calculated from the income statements of the panel of US firms from Compustat. Only then, using an iterative procedure, I can consistently calibrate the parameters of the production function (3.1) - the labor, intermediate input shares and returns to scale parameter - using the first order conditions of the model presented in Lemma 3.1. Details on the calibration procedure and adjustments can be found in Appendix F.

Prices and Labor Costs. Data on total hours worked and sectoral prices are provided by the Bureau of Labor Statistics ([BLS](#)). Total hours worked are then used to infer an aggregate wage rate from total labor expenditures recorded in the IO-tables. In order to ensure consistency with the model, where the wage rate is chosen as the numeraire, all prices are normalized by the common wage rate. Sector-specific prices are treated as input prices net of any interest cost on trade credit and are used to construct the respective quantities. The price of the final good is constructed using the results of profit-maximization problem of the final good producer. Since capital owned by firms is included into the model as a constant and set to its steady state level, the real interest rate on capital implied by a time preference rate of $\beta = 0.96$ is an annualized risk-free rate of 4 percent. The household's preference parameters, ϵ_L and ϵ_C are set such that

³The sample description and selection criteria are discussed in Appendix B.

$\epsilon_C : \epsilon_L = 0.4$, which implies that ϵ_L and ϵ_C vary around the values 0.5 and 0.2, a standard calibration used in macroeconomics also used in [BL\(2017\)](#).

While the calibration of the production parameters, prices and quantities is rather straight forward, in the remainder of this section I now discuss (a) the imputation of the shocks to the sector-specific risk premium on bank credit as in Equation (3.8) and (b) the calibration of the parameters of the credit management cost function in Equation (3.7).

Credit and Financial Shock Identification. The sector specific interest rate on bank credit is assumed to take on the following functional form as discussed in Chapter 3:

$$r_{kt}^B = x_0^B + r_{kt}^Z, \text{ where } r_{kt}^Z = \exp(z_{kt}^b) (\bar{\theta}_0^D + \theta_{kt}^C)^\mu x_0^B. \quad (4.2)$$

In other words, each sector is charged a risk premium over the federal funds rate. As a baseline measure for the risk premium, I employ the sectoral credit spreads derived in [Gilchrist and Zakrajšek \(2012\)](#) and provided to me by the authors, adjusted to match the calibrated bank interest rate expenditures imputed from the IO-tables. The "GZ-spread" is defined as the sectoral average of differences in the yields on corporate bonds and yields on Treasury securities of comparable cash flows and maturities. As outlined in Assumption 3.3, Chapter 3, the risk premium is assumed to be a convex function of the average leverage in the economy and the average trade credit share extended to customers. The components of the risk premium are calibrated as follows: First, the risk-free interest rate on bank credit, x_0^B , is set by calculating the time average (1997-2016) of the federal funds rate. And second, the average leverage⁴ in the economy, $\bar{\theta}_0^D$, as well as the sectoral average trade credit share, θ_{kt}^C , can be directly calculated from the data. In the spirit of the discussion in Chapter 2, the parameter μ is set to the weighted average of the corresponding estimated coefficient of sector-by-sector OLS-regressions of Equation (4.2) as described in Appendix F.1. As a result μ equals 1.2 such that a one percent increase in $\theta_{kt}^Z = \bar{\theta}_0^D + \theta_{kt}^C$ increases the bank risk premium by 1.2 percent.⁵ The implied shocks to the risk premium on bank credit, $\hat{z}_{kt}^b = \epsilon_{kt}^b$, can then be constructed directly from Equation (4.2). As a result, the calibrated equilibrium interest rates on trade credit exceed the interest rate on bank credit for the majority of sectors, thereby mapping the empirical observation on the relative cost of supplier and bank finance discussed in [Cuñat and García-Appendini \(2012\)](#). The interest rate on trade credit is inferred directly from Equation (3.8).

⁴The average leverage in the economy is set as the time average of the aggregate leverage, defined as the ratio of total long-term and short-term debt in total assets, over the entire sample period 1997-2016. The aggregate measure is calculated by aggregating the respective balance sheet data of the sample of US firms from Compustat within each period.

⁵The exponent, μ , is required to be greater than one to be consistent with the profit-maximization problem of the representative firm in sector k .

Credit Management Costs. The expenditures on non-productive labor or credit management costs, $C_k^T = w\ell_k^T$, are calibrated to be a share of total sectoral labor expenditures recorded in the IO-tables. The sector-specific share is set equal to the share of combined intermediate expenditures on management (NAICS = 55) and administrative services (NAICS = 561) in total sectoral intermediate input costs. The parameters of the credit management cost function (3.7) - $\{\kappa_k^B, \kappa_{0,ks}^T, \kappa_{1,ks}^T\}$ - are calibrated in two steps as described below. First, I rearrange Equation (3.21) which - after additional manipulation⁶ - yields

$$\theta_k^P = \left[\bar{\theta}_0^S - (\bar{\theta}_0^S)^2 \frac{\bar{\kappa}_0^T}{\bar{\kappa}_1^T} \right] + \left[\frac{(\bar{\theta}_0^S)^2}{\bar{\kappa}_1^T} \right] pq_k^E = \beta_0 + \beta_1 pq_k^E \quad (4.3)$$

where

$$\theta_k^P = \frac{\sum_{s=1}^M \theta_{ks} p_s x_{ks}}{\sum_{s=1}^M p_s x_{ks}} \quad \text{and} \quad pq_k^E = \underbrace{\left[\frac{\sum_{s=1}^M (p_s x_{ks})^2 \Delta_{ks}}{(\sum_{s=1}^M p_s x_{ks})^2} \right]}_{(b)} \underbrace{\left[\frac{\sum_{s=1}^M p_s x_{ks}}{(1 + r_k^B)} \right]}_{(a)}. \quad (4.4)$$

Note that θ_k^P is simply the share of aggregate accounts payable in total intermediate cost of production excluding interest rate payments. The variable pq_k^E denotes the effective net-interest expenditures on intermediate production inputs. It is defined as the weighted discounted intermediate cost of production excluding interest rate payments (a), where the weight is given by the sector-specific credit expenditure Hirschman-Herfindahl Index (HHI) (b). Similar to the interpretation of the traditional concept of the HHI-index measuring the degree of monopoly power in an industry (Shepherd, 1987), the Credit-HHI captures a sector's concentration of net-interest rate costs of production and ranges from $[\min(\Delta_k), \max(\Delta_k)]$ for $\Delta_k = \{\Delta_{ks}\}_{s=1}^M$. While the sign of the index depends on sector k 's relative cost of bank and trade credit, a higher value in absolute terms implies a higher dependency on the relative cost of credit from a particular supplier. To summarize, Equation (4.3) implies that the share of total intermediate cost of production obtained on trade credit is increasing in the effective net-interest cost of production, as the cost-parameter (κ_1^T) is assumed to be positive following the discussion of Section 2.1.

Since actual data on the interest rate on trade credit is not readily available, I rely on the mapping of the model to the data in order to obtain the data-counterparts of the share of aggregate accounts payable in total intermediate cost of production (θ_k^P) and the effective net-interest expenditures on intermediate production inputs (pq_k^E). At this point it should be noted, that while the accounts payable share is stationary, the interest-expenditures are non-stationary such that I use the detrended⁷ effective net-interest expenditures, $pq_{kt}^{E,h}$,

⁶For the purpose of the estimation of the respective coefficients in Equation (4.3), I first impose the assumption of *common* parameters such that $\kappa_{0,ks}^T = \bar{\kappa}_0^T$, $\kappa_{1,ks}^T = \bar{\kappa}_1^T$ and $\theta_k^S = \bar{\theta}_0^S \forall k, s$. The estimated coefficients are then used in the calibration of the *link-specific cost* parameters.

⁷The variable, pq_k^E , is first detrended by applying an hp-filter using a smoothing constant of 6.25 as suggested for annual data by Ravn and Uhlig (2002). The detrended series are then normalized by adding

in order to estimate the coefficients β_0 and β_1 in Equation (4.3). Equation (4.3) is then estimated by OLS using a panel of 45 sectors from 2000-2014, while controlling for time and sector fixed effects. The estimated coefficients and corresponding standard errors are reported below in parenthesis⁸ in Equation (4.5)

$$\theta_{kt}^P = \beta_0 + \beta_1 pq_{kt}^{E,h} + FE + \epsilon_{kt} \quad \text{and} \quad \hat{\theta}_{kt}^P = \underset{(0.005)}{0.11}^{**} + \underset{(0.115)}{0.24}^* pq_{kt}^{E,h} + \hat{F}E. \quad (4.5)$$

The estimated parameter $\hat{\beta}_1$ suggests that - since expenditures are measured in Mio dollars - increase of the net-interest expenditures by one Mio increases the share of intermediate expenditures obtained on trade credit by 24 percentage points. In the last step, the link-specific parameters are then calibrated by matching the estimated coefficient $\hat{\beta}_1$ in Equation (4.5) to the coefficient of the effective interest rate expenditures determining sector k 's trade credit share obtained from supplier s in Equation (3.22) as described in Appendix F. The remaining cost parameters, $\kappa_{0,ks}^T$ and κ_k^B , are calculated as a residual to ensure that Equation (3.22) and (3.7) hold.

At this point, it should be highlighted that three parameters are central in determining the magnitude of fluctuations in the economy with both bank and trade credit. The degree of convexity of the risk premium in the joint default probability measure, μ , as well as the average leverage in the economy, $\bar{\theta}_0^D$, determine (1) the relative size of the equilibrium interest rate on trade credit and (2) its volatility in response to bank credit shocks. In other words, an increase in the convexity of the mark-up function and an increase in the relative importance of the average trade credit share extended to customers for the risk premium, increases the level and volatility of the trade credit interest rate, thereby reinforcing the trade credit channel. Similarly, a decrease in the adjustment cost parameter $\kappa_{1,ks}^T$, increases the extend to which firms are able to adjust the composition of their borrowing portfolio between bank and trade credit, thereby increasing the substitution effect and therefore smoothing aspect of the trade credit channel.

Table 4.1 lists the (average) values of the calibrated production and financial parameters used in the simulations of the model. The values reported in this table are calculated as the four-year-average (2004-2007) prior to the crisis. In addition, the sample is split into net-lenders and net-borrowers according to the median net-lending position based on Definition 2.1 obtained from the data presented in Chapter 2. The p-values for the differences in means between the two groups are reported in the last column when applicable. The table reveals that the sub-samples differ both in their production and in their credit management technology. In particular, the p-values for the differences in means between net-borrowing and net-lending sectors suggest that the two groups of sectors differ in their capital, value-added (and therefore composite intermediate input) and final

the cyclical component to the sectoral time-mean of the interest expenditures, pq_k^E .

⁸*** p<0.01, * p<0.05, + p<0.1

demand shares at a 1-10% significance level. Net-borrowers tend to have a lower capital (α) and composite intermediate input ($1 - \eta$) share while their final demand share is significantly higher. This is in line with the empirical observation that sectors which are further downstream and thus closer to the final consumer are sectors producing with a more labor intensive technology (e.g. service industry). In the case of the credit management technology, net-borrowers are calibrated to have a higher linear cost parameter while the quadratic cost parameter is of similar magnitude in both groups.

Table 4.1: Calibrated Parameters

VAR		Description	All	NB	NL	p-Value
HH	ϵ_C	Income Elasticity	0.215			
	ϵ_L	Inv. Frisch Elasticity	0.546			
Production	α	Capital Share	0.344	0.275	0.417	0.002
	η	Value Added	0.465	0.512	0.416	0.062
	χ	DRS	0.833	0.834	0.832	0.917
	Ω^X	Intermediate	0.025	0.025	0.026	0.757
	Ω^F	Final	0.022	0.035	0.009	0.023
	z^q	Productivity	2.972	3.365	2.561	0.056
	k	Capital	13.66	15.81	11.42	0.355
Financial	μ	Bank Credit - Convex	1.2			
	$\bar{\theta}_0^D$	Bank Credit - Leverage	0.3			
	κ^B	CMan.Cost - Fixed	0.448	0.620	0.269	0.305
	κ_0^T	CMan.Cost - Linear	0.061	0.070	0.051	0.096
	κ_1^T	CMan.Cost - Quadratic	0.047	0.048	0.046	0.515
	$\bar{\theta}$	Av.TC-Demand	0.102	0.096	0.108	0.078
		#OBS	45	23	22	0

Note: This table describes the aggregate and the mean of the cross-sectional parameters used in the model simulations. The production and financial parameters, capital and productivity levels reported in this table represent the four-year-average (2004-2007) prior to the crisis. In case of sector-specific parameters the column (ALL) reports the mean of the parameter for the entire sample. The columns (NB) and (NL) report the mean for a subgroup of sectors based on the net-lending position - see Definition 2.1. The p-values for the differences in means between the two groups are reported in the last column.

4.1.2 Properties of the US Production and Credit Network

I now summarize selected characteristics of the imputed (endogenous) trade credit network of the US economy and contrast these with those of the complementary production-network. Note that while I assume the production structure, Ω , to be constant, the credit network, Θ , is endogenous along the intensive margin and varies over time. I first define a sector's average input- and credit-demand share as the row sum of $\Omega(\Theta)$ divided by the number of suppliers. Analogously, a sector's average sales- and credit-supply share is defined as the column sum of $\Omega(\Theta)$ normalized by the number of customers. Following

standard graph theoretical terminology (see e.g. [Carvalho, 2010](#)), the first measure is labelled the (weighted) in-degree, d_k^I , and the second measure refers to the (weighted) out-degree of sector k , d_k^O .⁹

Table 4.2: Correlation of Network Properties (2007)

2007	d_Ω^I	d_Θ^I	d_Ω^O	d_Θ^O	b_Ω^D	b_Θ^D	b_Ω^S	b_Θ^S
d_Θ^I	-0.22							
d_Ω^O	-0.36	-0.01						
d_Θ^O	-0.20	0.53	0.14					
b_Ω^D	0.18	0.00	-0.21	0.05				
b_Θ^D	0.18	-0.28	-0.26	-0.72	-0.17			
b_Ω^S	-0.35	0.00	0.94	0.06	-0.19	-0.18		
b_Θ^S	-0.17	0.40	0.24	0.45	0.19	-0.38	0.26	
θ^τ	-0.35	0.33	0.31	0.25	-0.04	-0.26	0.51	0.31

Note: This table reports the correlation between the following network properties of the pre-crisis average of the calibrated US production (Ω) and credit network (Θ) in 2007 as derived in Section 4.1: weighted demand (In-Degree, d_k^I) and supply shares (Out-Degree, d_k^O), demand (b_k^D) and supply centrality (b_k^S), net-lending position (θ_k^τ) as defined in Definition 2.1. A more detailed description of the standard graph theoretical statistics can be found in Appendix A.

Figures 4.1a and 4.1b plot the distribution of the average demand- and supply shares normalized by the median share of both networks in 2007¹⁰, highlighting a well known feature of the US production network (see [Carvalho, 2010](#)): While the US sectors exhibit a considerable degree of homogeneity along the extensive margin of sectoral demand, US sectors are heterogeneous in their role as input suppliers. These characteristics translate to the approximation of the US credit network due to the complementarity of both networks. Panel (c) of Figure 4.1 plots the distribution of the average net-lending position of sectors in 2007 and highlights that it exhibits similar characteristics as that of the sample of Compustat firms shown in Figure 2.2.¹¹

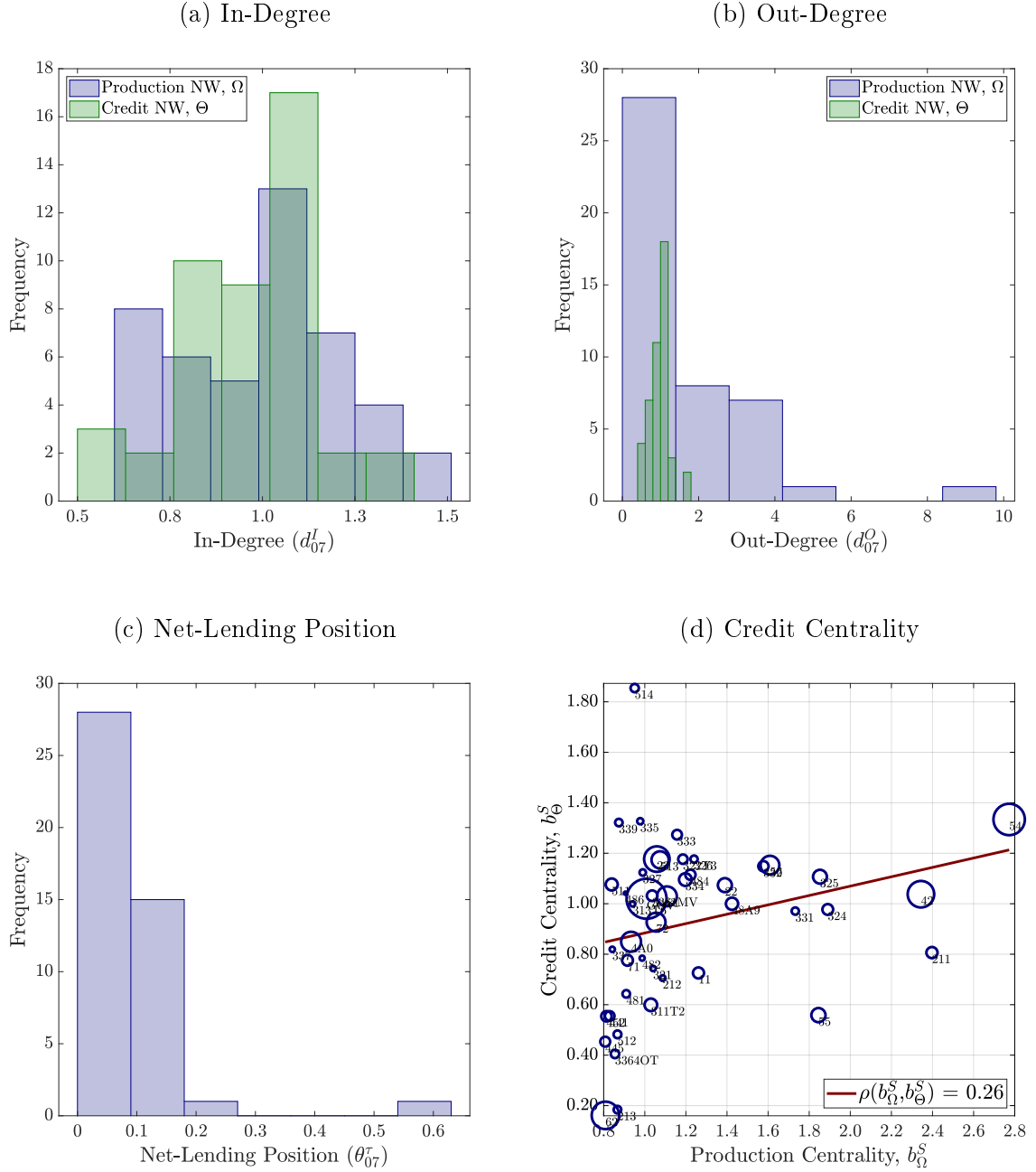
The complementarity of the network structures may raise the concern that mainly production rather than credit linkages among sectors affect the propagation of liquidity shocks. To address this concern, I consider the network concept of the (weighted)

⁹Note that due to the complementarity of the production and the credit network - e.g. a credit link between sector k and s exists if and only if sectors also engage in intermediate input trade - the cardinality of a sector's set of customers and suppliers for each network exhibit (almost) perfect correlation. Therefore, rather than analysing the extensive margin of each network structure, I focus on a combined measure capturing both the extensive and intensive margins of sectoral trade in goods and credit.

¹⁰It should be noted that while the qualitative features of the US production and credit network are constant over time, I chose the year(s) prior to the crisis to highlight these patterns. To be more precise, I calculate the respective statistics based on the imputed credit network in 2007 and based on the pre-crisis four year average (2004-2007) for the production parameters to be consistent with the calibration of the model.

¹¹Note that, there are only a few firms in the sample of Compustat firms used to generate Figure 2.2 in Chapter 2, that extend more credit to their customers than their up-front financing needs. At a sector level, I do not find sectors with a net-lending position strictly greater than one. Nevertheless, I still refer to sectors with a high ratio of accounts receivable to bank credit as net-lenders.

Figure 4.1: Properties of the US Production and Credit Network (2007)



Note: The network statistics have been calculated using the calibrated production parameters and trade credit shares of 2007 as derived in Section 4.1. Panel (a) and (b) plot the distribution of the average demand- (In-Degree) and supply-shares (Out-Degree) of the production and the credit network, normalized by the respective median. Panel (c) depicts the distribution of the average net-lending position as defined in 2.1. Panel (d) plots the relation between the production- and the credit-supply centrality of sectors. The size of one observation represents the relative importance of the sector in the economy measured by the share of a sector's average pre-crisis (2004-2007) value added in total value added. A more detailed definition of the standard graph theoretical statistics can be found in Appendix A.

Bonacich centrality, $b_k^{D(S)}$. It describes the systemic importance of a sector based on the total weighted number of walks between two sectors and is similar to the concept of the Leontief-Inverse common to any input-output model. Panel (d) of Figure 4.1 plots the relation between the pre-crisis average of the production and the credit centrality of sec-

tors in 2007 and Table 4.2 reports the correlation of network properties. In particular, the pairwise correlation coefficient of the production and credit supply centrality of sectors, $\rho(b_{\Omega}^S, b_{\Theta}^S)$, is positive but of a lower magnitude. This suggests that despite a certain degree of complementarity between the production and credit network, they are not perfectly correlated such that any shocks transmitted via the inter-firm credit linkages have different implications for economic dynamics.

To summarize, Figure 4.1 and Table 4.2 highlight three properties of the production structure and the calibrated trade credit network in the US:

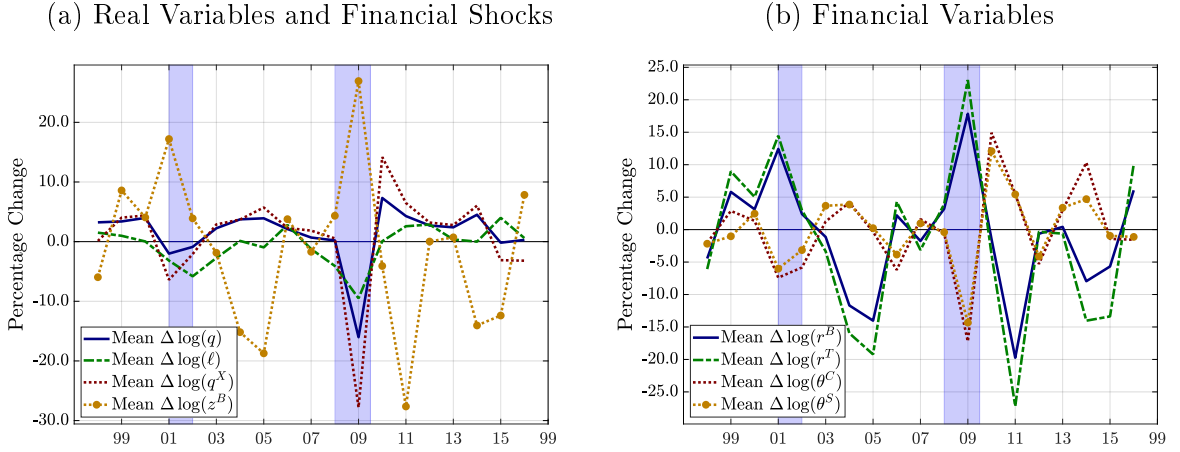
- (1) There is heterogeneity among sectors when supplying goods and credit to their customers. In particular, the distribution of sales- and credit-supply shares is heavily skewed to the left such that only a few sectors act as major suppliers of goods and credit in the US economy.
- (2) The systemic importance of a sector based on the production structure is weakly positively correlated with its credit centrality. In other words, a sector which plays a central role in the trade of goods is also more likely to play a central role in the provision of supplier credit.
- (3) The net-lending position of a sector is positively correlated with the overall systemic importance of a sector as a supplier of credit.

4.1.3 Business Cycle Statistics

Following the period-by-period mapping of the equilibrium of the model to the corresponding data on the US economy discussed at the beginning of this section, I now document business cycle statistics for selected real and financial variables. Panel (a) of Figure 4.2 plots the sectoral mean of the implied banking shock and of the log-change of selected production inputs across time. Panel (b) of Figure 4.2 plots the average log-changes in the interest rates on bank and trade credit as well as in the trade credit shares. The sample period covers two recessions: the dotcom-crash in 2001 and the 2008-2009 financial crisis.

As documented in Chapter 2, real US GDP dropped by approximately 2.6% during the crisis. Figure 4.2a documents that the implied shock to bank risk premia rose by 26.9% and lead to an increase of bank and trade credit interest rates by 17.8% and 23.1%, respectively. Average sectoral output declined by approximately 16.0% caused by a drop in labor and the composite intermediate input by 9.5% and 27.8%, respectively. At the same time, the average trade credit share extended to customers declined by 17.2% and the average share of intermediate expenditures obtained on trade credit dropped by 14.3%.

Figure 4.2: Data - Mean Changes



Note: This figure plots the log-change in percent of the time series of selected real and financial variables calculated based on the data discussed in Section 4.1 from 1997-2016. Panel (a) plots the sectoral mean of the implied financial shock (z_k^B), the log-change of real output (q_k), labor (ℓ_k) and the intermediate input composite (q_k^X). Panel (b) plots the average log-change in the interest rate on bank (r_k^B) and trade credit (r_k^T) as well as in the trade credit shares (θ_k^C , $\theta_k^S = \sum_{s=1}^M \theta_{ks}/M$).

For each sector, I now calculate the standard deviation of log-changes in the variables of interest. I also derive the within sector correlation between (a) log-changes in output and (b) log-changes in the cost of bank credit and the remaining real and financial variables. The cross-sectional mean of the business cycle statistics are reported in Table 4.3. In addition, I split the sample of sectors based on their net-lending position defined in 2.1 and obtained from the data presented in Chapter 2: a sector is counted as a net-lender if its net-lending position is above the median of the distribution of net-lending shares.

Output, Labor and Intermediate Inputs. Over the entire sample period, 1997-2016, average sectoral output exhibits a volatility of around 7%. Total sectoral hours worked and the intermediate composite show a standard deviation of approximately 6.5% and 14.0%, respectively. In other words, on average, labor demand is less volatile whereas the demand for the composite intermediate inputs is more volatile than output. Furthermore, log-changes in output are positively correlated with both changes in production inputs. The business-cycle statistics of the data-counterparts of the respective model variables on sectoral output, labor and the intermediate composite for the entire sample are similar to those reported in BL(2017). I now take a closer look at the mean and the standard deviation of log-changes in both subsamples of sectors. The p-values for the differences in means between net-borrowing and net-lending sectors suggest that while there is no significant difference in the volatility or output-correlation, the two groups of sectors seem to differ in the average growth rate of employed labor and intermediate inputs at a 10% significance level.

Cost of Credit and Trade Credit. The imputed sectoral interest rates on bank and trade credit exhibit a standard deviation of 11.4% and 16.8%, respectively and are thus

both more volatile than sectoral output. Table 4.3 indicates that the implied interest rate on trade credit is more volatile than the interest rate on bank credit, which relates to the stylised facts presented in Chapter 2 on the relative volatility of accounts payable and liabilities. In addition, both interest rates comove strongly. The average trade credit share extended to customers, θ^C , and obtained from suppliers, θ^S , are more volatile than sectoral output but less volatile than the implied costs of trade credit. In addition, they are negatively correlated with the cost of bank finance such that an increase in the cost of bank credit decreases either shares. This is due to the fact that while the interest rates on bank and supplier credit comove strongly, the latter exhibits a higher standard deviation. Consequently, firms shift their borrowing portfolio towards bank finance in response to an increase in credit market frictions as discussed in Chapter 2. Interestingly, the correlation between the cost of bank credit and the interest charged on trade credit as well as the average trade credit share obtained from suppliers seems to be significantly higher for the group of sectors classified as net-borrowers at a 10% significance level. In other words, as net-borrowers face a higher cost of bank finance, they are more likely to increase their lending rates and shift more towards bank finance. This suggests that the substitution effect of trade credit discussed in Chapter 2 may be more pronounced for net-borrowers.

Table 4.3: Data - Time-Series Correlation

(a) Real Variables

Total (97-16)					
	VAR	All	NB	NL	p-Value
MEAN	q	0.014	0.017	0.010	0.290
	ℓ	-0.006	-0.001	-0.012	0.054
	q^X	0.008	0.016	0.000	0.072
	z^B	-0.013	-0.017	-0.008	0.260
STDV	q	0.069	0.068	0.069	0.921
	ℓ	0.065	0.052	0.078	0.282
	q^X	0.140	0.133	0.147	0.663
	z^B	0.154	0.152	0.155	0.893
CORR	(q, ℓ)	0.557	0.601	0.512	0.440
	(q, q^X)	0.809	0.784	0.834	0.384
	(q, z^B)	-0.418	-0.385	-0.453	0.300
	#OBS	45	23	22	

(b) Financial Variables

Total (97-16)					
	VAR	All	NB	NL	p-Value
MEAN	r^B	-0.008	-0.011	-0.005	0.160
	r^T	-0.018	-0.020	-0.016	0.672
	θ^C	-0.001	-0.003	0.000	0.615
	θ^S	-0.000	-0.002	0.002	0.365
STDV	r^B	0.114	0.114	0.114	0.978
	r^T	0.168	0.169	0.167	0.952
	θ^C	0.134	0.130	0.138	0.658
	θ^S	0.092	0.078	0.107	0.081
CORR	(r^B, r^T)	0.922	0.953	0.890	0.065
	(r^B, θ^C)	-0.239	-0.258	-0.220	0.624
	(r^B, θ^S)	-0.341	-0.401	-0.277	0.104
	#OBS	45	23	22	

Note: This table reports the time-mean of the cross-sectional mean, the standard deviation and the correlation with output and the bank interest rate of the log-change of the following variables: output (q_k), labor (ℓ_k), the intermediate input composite (q_k^X), the interest rate on bank (r_k^B) and trade credit (r_k^T), the trade credit shares ($\theta_k^C, \theta_k^S = \sum_{s=1}^M \theta_{ks}/M$). The first column reports the business cycle statistics for the entire sample. The second and third column report the same statistics for a subgroup of sectors based on the net-lending position Definition 2.1. The p-values for the differences in means between the two groups are reported in the last column.

In the previous paragraphs, I have focused on the mapping of the model to the data and their business cycle properties. Before moving on to the main quantitative application of the model, I will elaborate further on the data-counterpart of sectoral credit distortions in the model and on the trade credit usage of sectors. In particular, the discussion in next

section will be informative for the set-up of the counterfactual exercises conducted in Section 4.2, in order to quantitatively assess the role of trade credit linkages for the propagation of financial shocks using the model framework introduced in Chapter 3.

4.1.4 Credit Distortions and Sector Heterogeneity

Chapter 2 highlighted that trade credit plays an important role in an economy by affecting the propagation of financial shocks and subsequently aggregate and sectoral outcomes. In particular, the data suggests that the heterogeneity in the usage of trade credit across sectors had different implications for sectoral output growth in the recent 2008-2009 recession: Sectors who were more exposed to and/or experienced a greater decline in their net-lending position experienced a greater drop in output during the crisis as discussed in Chapter 2. While these statements are based on bivariate correlations patterns observed in the data, they also raise the following two questions: (1) What other sectoral characteristics contributed to the sharp decline in output in 2009 and (2) How do they relate to the heterogeneous usage of trade credit across firms?

In order to address these question, I discuss the effect of differences in productivity levels, and in the structure of trade and credit linkages on sectoral distortions, changes in credit spreads and output growth during the crisis. While real output data is readily available, I rely on the mapping of the model to the data discussed in Section 4.1, to obtain time series of sectoral productivity (z_k^q) and financial shocks to the bank risk premium (z_k^b). The level of sectoral distortions is measured by the combined credit wedge of the marginal cost of production (ϕ_k^V), defined in Equation (3.19). Furthermore, I calculate the Bonacich centrality (b_{Ω}^S) of a sector as described above and the net-lending position (θ_k^r) to capture the systemic importance of a sector as a supplier of inputs and credit, respectively. The inspection of the bivariate correlation coefficient between the average pre-crisis level and the change of the respective variables of interest during the 2008-2009 Financial Crisis presented in Table 4.4, suggests the following.

Table 4.4: Credit Distortions and Sector Heterogeneity

VAR	ϕ_k^V	$\Delta \log(z_k^b)_{09}$	$\Delta \log(q_k)_{09}$	z_k^q	VAR	$\Delta \log(q_k)_{09}$
z_k^q	0.33	-0.10	0.29	1.00	z^q	0.29
θ_k^r	0.21	0.31	-0.36	-0.16	$\Delta \log(z_k^b)_{09}$	-0.56
$b_{\Omega,k}^S$	0.03	0.07	-0.26	0.18	$\Delta \log(\theta_k^r)_{09}$	0.55

Note: This table reports the cross-sectional correlations between the following variables: (q) real output, (z^q) productivity, (θ^r) net-lending position, (b_{Ω}^S) Bonacich-Supply centrality, (ϕ^V) credit wedge of marginal cost of production. The level of a variable is calculated as the pre-crisis average (2004-2007), while the log-change refers to the growth rate of the variable in 2009.

More productive sectors seem to be more distorted but experienced a smaller decline in their output during the crisis than less productive sectors, which may be partially due to smaller shocks to their bank risk premium. While there is only weak evidence that sectors who extend more trade credit relative to their upfront financing-needs exhibit lower productivity levels, they face higher distortions, experienced a higher shock to their cost of bank credit and subsequently a stronger decline in output during the crisis. The positive correlation between the net-lending position of a sector and shocks to its bank risk premium is in line with the findings on the positive relationship between the interest rate on bank credit and the share of total sales extended on trade credit in Chapter 2. Differences in the production structure as measured by the supply centrality of the sector seem to play only a minor role for the level of distortions or the size of the shock to the bank risk premium. However, the correlation coefficient in Table 4.4 indicates that more central sectors also experienced a greater decline in output in 2009.

Following up on the previous concern raised in Section 4.1.2 regarding the complementarity of the production and credit network between firms, the correlation patterns presented in Table 4.4 do suggest that credit linkages indeed may have a stronger impact on distortions and changes in output in response to financial shocks than differences in the production structure. However, they also raise the question to what extent the observed changes in output can be attributed to (changes) in the credit network since net-lenders have also been more affected during the crisis according to the correlation patterns recorded in Table 4.4. In order to quantify the role of credit linkages for the propagation of financial shocks and disentangle the effect of the trade credit channel from any effects induced by differences productivity levels or financial shocks, I simulate the model while abstracting from any changes in productivity and conduct a variety of counterfactual exercises, which I will now discuss in greater detail.

4.2 Quantitative Application

In view of the facts presented on trade credit in the US economy in Chapter 2, the first question I address quantitatively through the lens of the model introduced in Chapter 3 is, to what extent does the interdependency of distortions created by trade credit linkages affect business cycle comovement, aggregate fluctuations and economic outcomes. For this purpose, the model-implied time series are obtained by feeding in the financial shock series imputed from the GZ-credit spreads and solving numerically for the equilibrium of the static economy. Any additional variation originating from changes in (1) production and financial parameters, (2) capital and (3) productivity and foreign trade shocks is excluded by keeping the respective variables at their four-year-average (2004-2007) prior to the crisis as reported in Table 4.1. The data-counterparts of the variables of interest are obtained via direct period-by-period mapping of the equilibrium of the static economy presented in Chapter 3 to the data as described in Section 4.1.

In the second part of this application, I focus on the assessment of the role of trade credit linkages for the propagation of financial shocks during the 2008-2009 Financial Crisis. Keeping in mind the propagation mechanism introduced by endogenous trade credit linkages as discussed in Chapter 3, Section 4.2.2 addresses the following questions using simulations of the model: (a) To what extent do credit linkages amplify or dampen the response of output relative to an economy with bank finance only. (b) Does the endogenous adjustment of credit costs and portfolios reduce or amplify volatility in an economy? (c) In view of the results of Proposition 4, what is the quantitative role of net-lenders for the propagation of financial shocks.

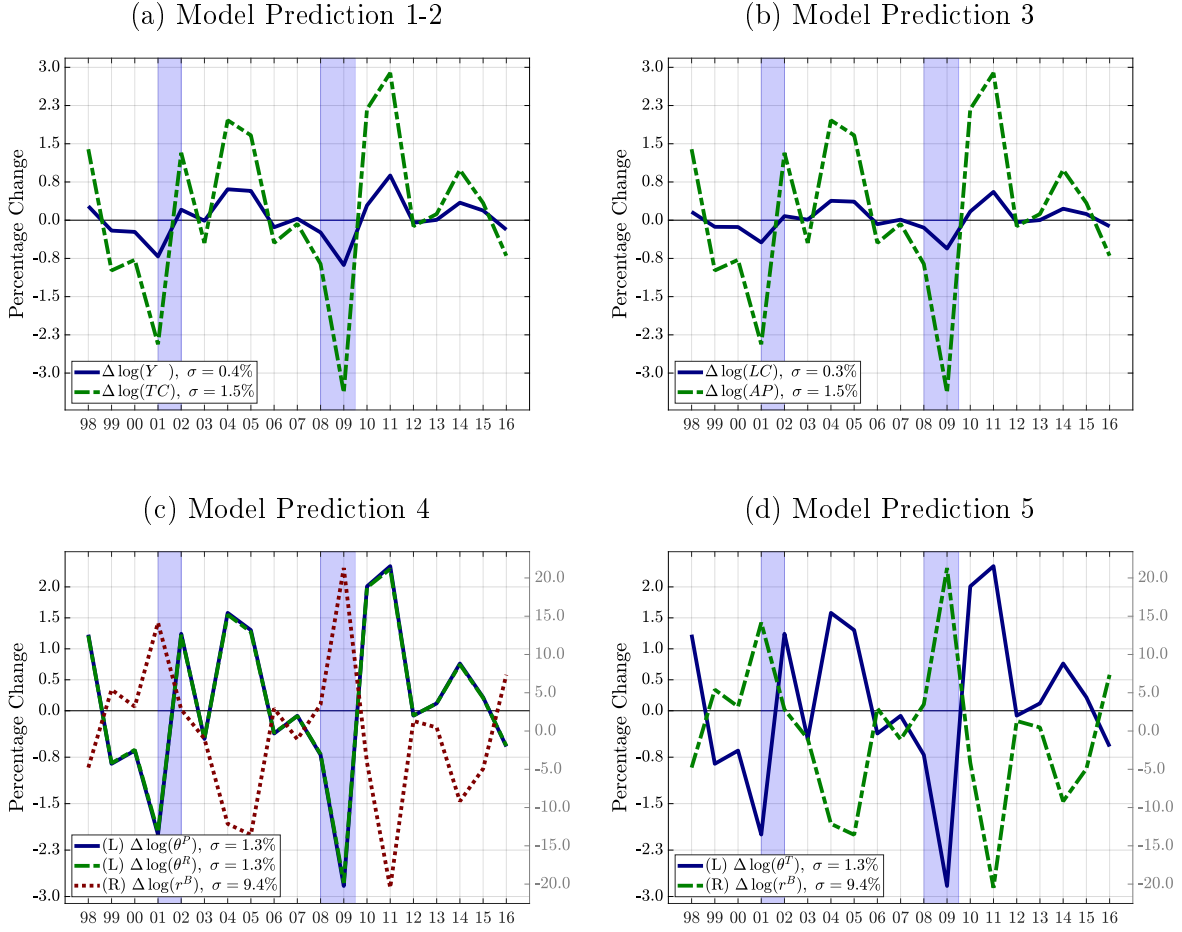
Section 4.2.1 now examines the model performance based on its ability to re-produce fluctuation patterns of the variables of interest observed in the data for the sample period (1997-2016) discussed in Chapter 2.

4.2.1 Business Cycle Properties Through the Lens of the Model

In order to provide a first assessment of the ability of the model to generate business cycle patterns of both real and financial variables as shown in Chapter 2, I first reproduce Figure 2.1 using the model-implied series only. As evident from Figure 4.3, the model indeed reproduces *qualitatively* the business cycle features of trade credit and the changes in the short-term borrowing portfolio observed in the data when accounting for the timing restrictions discussed in Chapter 2. First and foremost, the model replicates a key feature of the recent financial crisis: (M5) As credit spreads rose during the financial crisis, the supplier credit market contracted immediately and firms drew down their bank credit lines substituting supplier with bank credit. In addition, the model-simulated series also imply

that in response to financial shocks to the bank risk premium only: (M1) The growth rate of the volume of trade finance is pro-cyclical with the growth rate of current real GDP; Trade credit is more volatile than the growth rate of (M2) total value added and (M3) firms' liabilities. The model also predicts that (M4) the share of accounts payable and receivable in total costs of production and sales are negatively correlated with aggregate credit spreads in the economy.

Figure 4.3: Model-Implied Business Cycle Properties of Trade Credit



Note: The panels in this figure replicate the graphs presented in Figure 2.1 and plot the evolution of the log-change in percent of the simulated time series of aggregate US GDP (Y), Accounts Payable (AP), Accounts Receivable (AR), Current (LC) Liabilities, the share of AP in Current Liabilities (θ^T), the aggregate GZ-spread (GZ), the share of AP in Total Costs of Goods Sold (θ^P) and the share of AR in Total Sales (θ^R). All variables are reported in real terms using the aggregate price-index. The model-simulations are based on financial shocks only. The figures also report the standard deviation of the respective series in percent.

Quantitatively, the average simulated IO-adjusted risk premium features 19.8% of the volatility of the aggregate GZ-spread. The model simulations based on the imputed financial shock series demonstrate that the model is able to account for 25.5% of the variation in output, 7.6(5.0)% of the variation in total (current) liabilities and 25.6% of the variation in supplier credit. Taking a closer look at the credit composition, the model also reproduces 37.6% of the fluctuations in the credit composition of short-term borrowing and approximately 18.9(23.3)% of the variation in the share of trade credit in

total costs and sales, respectively. I thus conclude that the model is a reasonable tool for the analysis of trade credit linkages and the effect on business cycle comovements and aggregate fluctuations.

Table 4.5 presents the time series correlation for selected aggregate real and sector-level financial variables with their counterpart in the data across time, using a 10-year-rolling window. The correlation between the model-implied growth rate of aggregate GDP (labor) and the actual rate observed in the data is approximately 63(59)% on average across time. The model fits particularly well during later years in the sample.

Table 4.5: Model-Fit - Time-Series Correlation

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	Mean	Std	Min	Max
Crisis	0.22	0.40	0.50	0.40	0.30	0.30	0.30	0.30	0.30	0.34	0.08	2008	2010
$\Delta \log(Y)$	0.42	0.39	0.39	0.72	0.75	0.73	0.73	0.77	0.73	0.63	0.17	2010	2015
$\Delta \log(C)$	0.26	0.23	0.24	0.64	0.73	0.73	0.73	0.78	0.75	0.57	0.24	2009	2015
$\Delta \log(L)$	0.31	0.31	0.32	0.66	0.73	0.77	0.74	0.72	0.74	0.59	0.21	2009	2013
$\Delta \log(\Phi^Z)$	0.62	0.62	0.75	0.76	0.66	0.57	0.58	0.63	0.52	0.63	0.08	2016	2011
$\Delta \log(\Phi^L)$	0.37	0.34	0.43	0.53	0.41	0.43	0.50	0.49	0.41	0.43	0.06	2009	2011
$\Delta \log(AR)$	0.67	0.66	0.72	0.86	0.86	0.86	0.87	0.86	0.87	0.80	0.09	2009	2016
$\Delta \log(AP)$	0.52	0.50	0.61	0.80	0.85	0.84	0.87	0.88	0.90	0.75	0.16	2009	2016
$\Delta \log(r^T)$	1.00	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	2009	2016
$\Delta \log(\theta)$	0.47	0.46	0.53	0.75	0.78	0.76	0.78	0.79	0.79	0.68	0.14	2009	2015
$\Delta \log(\theta^C)$	0.50	0.48	0.50	0.79	0.78	0.78	0.79	0.78	0.78	0.69	0.14	2009	2014
$\Delta \log(\phi^X)$	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.00	2012	2008

Note: This table presents the time series correlation for selected aggregate real and sector-level financial variables with their counterpart in the data across time, using a 10-year-rolling window. The indicated years represent the end-dates of a 10-year-rolling window used to calculate the time-series correlation. The variable *crisis* shows the frequency the US-economy spent in crisis based on NBER-recession dates during the 10-year-period.

At a sector level, panel (a) of Figure 4.5 shows the cross-sectional correlation between output growth during crisis as observed in the data and output-growth generated by the simulation of the model in response to financial shocks only. As evident from panel (a) the model is also able to capture output dynamics at a sector level as observed in the data.

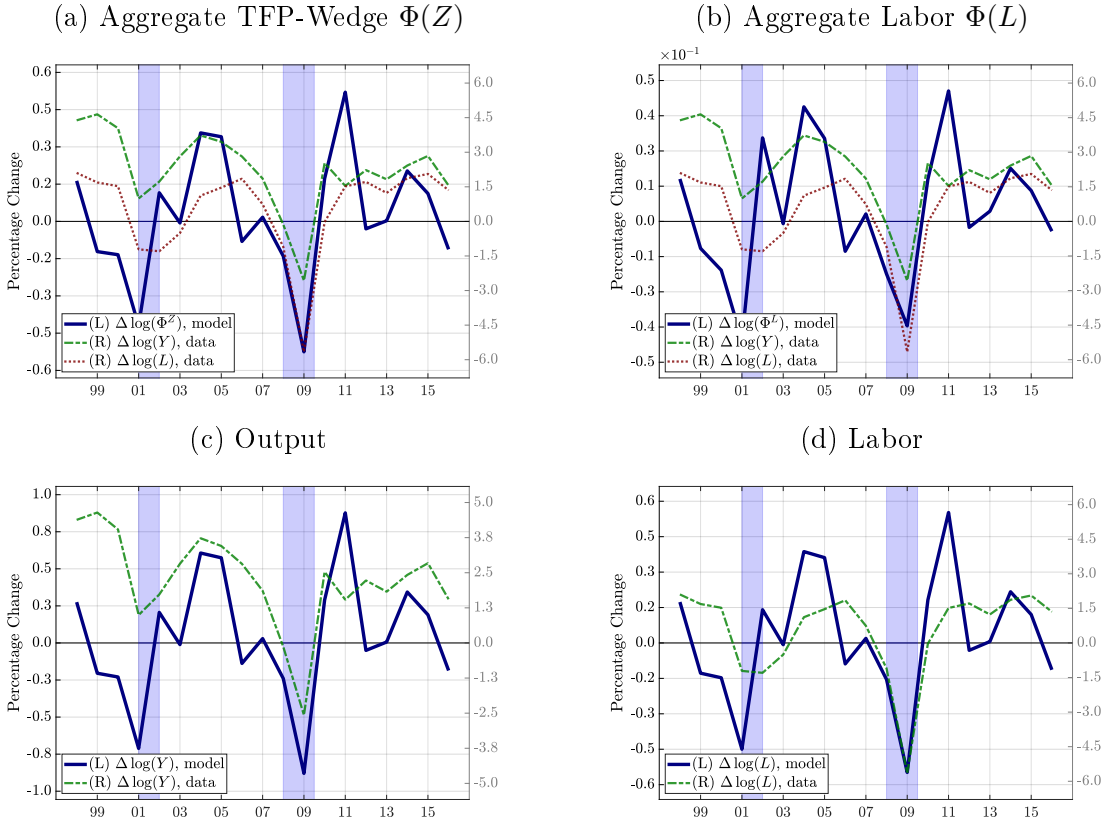
4.2.2 The Role of the Credit Network during the Great Recession

In the previous paragraphs, I have shown that the model is able to reproduce business cycle patterns of trade credit similar to those observed in the data. I now evaluate the effects of trade credit linkages on aggregate distortions and business cycle fluctuations in the US economy during the 2008-2009 Financial Crisis in order to provide answers to the questions posed at the beginning of the section: (1) Did the interfirm credit network amplify or smooth financial shocks during the Great Recession in comparison to an economy without

trade credit?, and (2) To what extent does the trade credit channel contribute to aggregate fluctuations?

Financial Frictions and The Business Cycle. The existence of a working capital constraint for firms generates demand for ex-ante liquidity which is met by obtaining credit from both banks and suppliers. The cost of drawing credit lines from either diverts funds from productive inputs which manifests itself as an aggregate efficiency and labor wedge as shown in Chapter 3. Panel (a) and (b) of Figure 4.4 plot the predicted percentage changes in the aggregate TFP and the aggregate labor wedge in response to a shock to the cost of bank credit as well as the log-changes in observed aggregate output and labor measured against the right axis. As can be seen in the figures, the changes in either wedge co-move strongly with aggregate output and labor in the data. Panel (c) and (d) of Figure 4.4 present the model-predicted percentage changes of aggregate output and labor on the left axis against those observed in the data. The model predicts that changes in the financial frictions alone account for approximately 34.2% of the actual drop in output reported in Chapter 2 and 9.7% of the drop in labor during the 2008-2009 Great Recession.

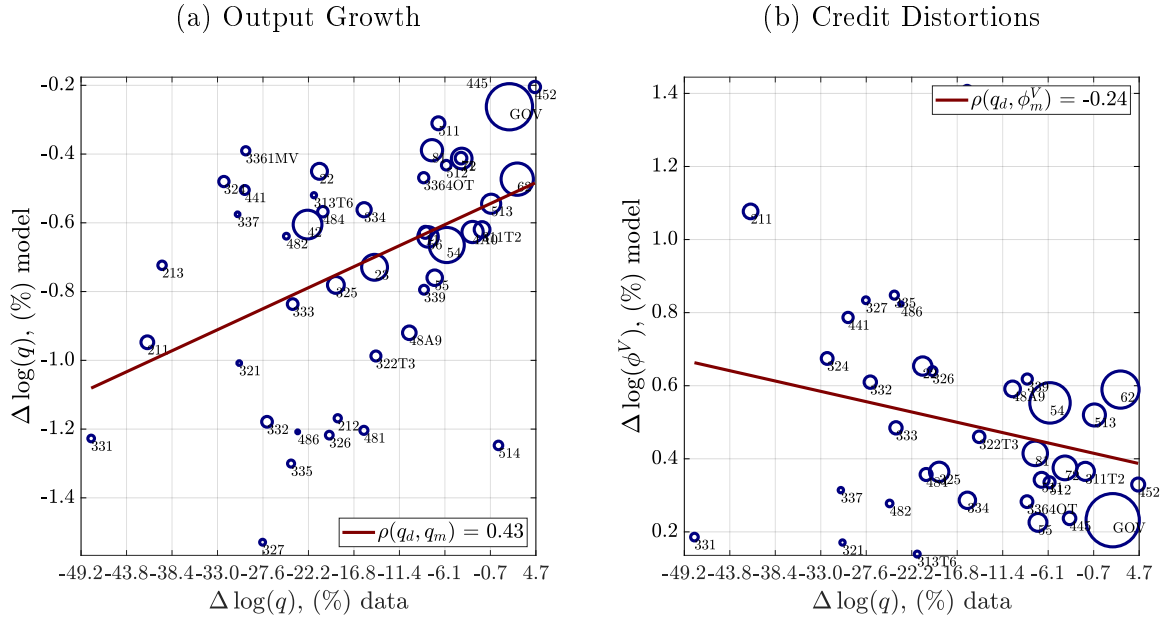
Figure 4.4: Model-Fit - Aggregate Outcomes



Note: Panel (a) and (b) in this figure plot the model-implied log-changes in the aggregate TFP and the aggregate labor wedge in response to shocks to the cost of bank credit only. The log-changes of observed aggregate output and labor are measured against the right axis. Panel (c) and (d) plot both the log-changes of aggregate output and labor as implied by the model simulations in response to shocks to the cost of bank credit on the left axis against those observed in the data. All log-changes are reported in percent.

At a sector level panel (b) of Figure 4.5 depicts the cross-sectional correlation between output growth during crisis as observed in the data and the log-change of sectoral credit wedges, ϕ_k^V , distorting the marginal cost of production in 2009 as defined in Equation (3.19). It follows that sectors who experienced a stronger increase in distortions also exhibit a greater drop in output during the crisis, which is in line with the predictions of the model.

Figure 4.5: Model-Fit - Sectoral Output Growth in 2009



Note: This figure depicts the correlation between sectoral output growth observed in the data and (a) sectoral output growth generated by the simulation of the model using financial shocks to the cost of bank credit only; (b) the log-change of sectoral credit wedges, ϕ_k^V , distorting the marginal cost of production defined in Equation (3.19) during the financial crisis in 2009. The percentage changes are reported in percent. The calculation of the cross-sectional correlations are based on the full sample in panel (a) and based on a reduced sample by exclusion of one outlier in panel (b). The size of one observation represents the relative importance of the sector in the economy measured by the share of a sector's average pre-crisis (2004-2007) value added in total value added.

As emphasized in BL(2017) and further discussed in the theoretical section, the cost of credit affect aggregate output through two channels: changes in the aggregate TFP and the labor wedge. A decomposition of the log-changes in aggregate output and labor into contributions of either channel suggests that most of the changes are attributed to changes in the efficiency rather than the labor wedge. This result contrasts the findings in BL(2017) for two reasons. First, differences in the calibration strategy of aggregate prices and financial shocks may affect the relative importance either channel. Second, and more importantly, wedges are interdependent.

Having established that financial frictions are able to account for a non-negligible fraction of movements in aggregate variables, I now focus on the quantification of the role played by interlinked distortions in the form of trade credit linkages among firms during the financial crisis. In order to address the questions posed at the beginning of this section, I conduct the following exercises: (a) The first simulation evaluates the contribution of

the existence of trade credit linkages to the drop in output during the recent recession by comparing the response of the variable of interest in the model economy introduced in Chapter 3 to that generated in a counterfactual economy with bank credit only. (b) Second, I decompose the general equilibrium response of the variables into their partial equilibrium counterpart derived by keeping both trade credit interest rates and shares at their steady state level. The difference between the general and partial equilibrium response can be attributed to the trade credit channel, highlighting the effect of the endogenous adjustment of the volume and cost of trade credit on the aggregate economy. (c) The third and fourth exercises seek to address the concerns raised in Section 4.1.4 by comparing the response of the benchmark economy with those of an economy featuring symmetric credit linkages and symmetric shocks to the bank risk premium, in order to disentangle the role played trade credit from other sources of heterogeneity. (d) In a last exercise, idiosyncratic shocks to different groups of sectors are considered in order to quantify Proposition 4 introduced in Chapter 3.

(a) TC-Multiplier. Since the model nests the economy presented in BL(2017) if no trade credit linkages are considered, the comparison of the predictions produced by a model with trade credit to the otherwise equivalent model without any credit linkages provides a clear way to disentangle the effects of the credit network from those of the inter-sectoral trade network alone. For this purpose, similar to BL(2017), I first define an equivalent economy, $\mathcal{E}(0)$, and the Trade Credit Multiplier as follows

Definition 4.1 (Equivalent Economies). *Let $\mathcal{E}(0)$ be an equivalent economy to an economy with both production and credit linkages, $\mathcal{E}(\theta)$, with production linkages only. Then $\mathcal{E}(0)$ features the same observed input prices net of any credit costs and the same observed nominal sales, input expenditures and value added as in $\mathcal{E}(\theta)$.*

Definition 4.2 (Trade Credit Multiplier). *Let $\mathcal{E}(\theta)$ be an economy in which firms finance their working capital requirements with both trade and bank finance and let $\mathcal{E}(0)$ be the corresponding equivalent economy. Consider the same sector-specific shocks across both economies. The "trade credit multiplier" is the ratio between the percentage drop in a variable of interest, e.g. aggregate output, generated by an economy with both trade and bank finance and an equivalent economy with bank finance only.*

I then simulate both economies, an economy with bank and supplier credit, $\mathcal{E}(\theta)$, and an equivalent economy where firms finance their working capital requirements with bank credit only, $\mathcal{E}(0)$, using the same financial shocks to the sector-specific bank risk premium. The first two rows of Table 4.7 report the percentage change in aggregate output, labor and both the efficiency and labor wedge in 2009 for the economy introduced in Section 3 and its equivalent counterpart. In addition, column (5) to (7) also report the average percentage change in sectoral output, labor and credit wedges.

The resulting trade credit multiplier \mathcal{M} ranges from 1.63 for aggregate labor to 2.19 for the aggregate efficiency wedge, and from 2.11 to 4.19 for the average sectoral labor and output response, implying that the credit network itself generates a considerable amplification of distortions. Since the model including both production and credit linkages captures approximately one third for the drop in aggregate real GDP, I conclude that about 16 percent of the drop in aggregate output can therefore be attributed to the existence of trade credit per se. In addition, I have also simulated an equivalent economy without any credit management costs which represents the economy introduced in BL(2017). The comparison of the response of the respective variables and the resulting trade credit multipliers are reported in Table F.2 in Appendix F. The trade credit multiplier of all variables are of similar magnitudes, with the multiplier of output being only slightly lower as any changes in distortions will have stronger effects on labor markets due to the absence of a fixed labor demand for non-productive labor.

The intuition of this result in either counterfactual is as follows: In an economy with bank finance only, a shock to the cost of external funds overall increases the cost production. Subsequently, prices increase and sectoral and aggregate output decrease. As discussed in detail in Section 3.2, in an economy where firms finance their production using both bank and supplier credit, an increase in sectoral bank risk premia also translates into an increase in the cost of trade credit as shown in Lemma E.5. Consequently, total credit cost of production increase by more relative to an economy with bank credit only. As predicted by the model and observed in the data, firms adjust their credit portfolio by moving towards bank finance during the crisis since the interest rate on trade credit exhibits a stronger increase than the interest rate on bank credit. However, these adjustments are not enough to undo the exacerbating effecting of credit linkages on the drop in output *relative* to an economy without credit relations among firms. This observation therefore translates into a trade credit multiplier greater than one as recorded in Table 4.7. Interestingly, the credit linkages reduce the effect of financial shocks on the aggregate labor wedge. This suggests that the credit network does not only increase the volatility of both the marginal product of labor and the real wage rate, it also increases their comovement, thereby reducing the volatility of the aggregate labor wedge.

(b) TC-Mechanism. Having established that the credit network itself considerably amplifies the propagation of financial shocks, the question remains whether in an economy with both bank and trade credit the smoothing or the amplification mechanism of the trade credit channel introduced in Chapter 3 dominates: An increase in the cost of bank credit of sector k leads to the following adjustments of trade credit costs and volumes: First, the interest rate on trade credit charged by sector k increases which, in addition to any shocks to the bank risk premium of k 's customers, will further increase the cost

of production of all customers of sector k . (see Lemma E.5 and 3.6) As such, for given credit shares the increase in the cost of supplier credit amplifies idiosyncratic shocks to the interest rate on bank credit. Second, since the model generates a more volatile response of the cost of trade than the cost of bank credit, firms shifted their borrowing portfolio towards bank finance (see Lemma E.4 and Figure 4.3d), thereby dampening the effect of the increase in the cost supplier finance.

In order to quantify the actual trade credit channel and its effect on the volatility and response of output during the crisis, I first calculate the partial equilibrium response of the variables of interest by keeping both the interest rate on trade credit as well as the trade credit shares at their steady state level (PE_R). The difference between the general and partial equilibrium response can thus be attributed to the trade credit channel overall. The effect of an endogenous adjustment of the credit portfolio on the volatility and response of output is further isolated by comparing the respective statistic in general equilibrium to its counterpart in partial equilibrium where only the credit portfolio remained at its equilibrium value (PE_T).

Table 4.6 reports the results of both partial equilibrium exercises for aggregate output and average sectoral output: The first observation is that, overall, the effect of the trade credit channel on aggregate and sectoral volatility and output are rather small. The total effect of the trade credit channel on both the volatility of output across sectors and sectoral output growth during the crisis is negative. With reference to the results reported in Table 4.6, the endogenous adjustment of the interest rates charged on trade credit and of credit portfolio increases sectoral output volatility by 2.30% in 1997-2016 and increased the drop in sectoral output by 1.74% on average. This is due to the fact that the amplification channel of an adjustment of the cost of trade credit dominates and is only partially off-set by the adjustment of credit shares, which reduces volatility and the decline in output by 1.32 and 1.50%, respectively.

Table 4.6: Decomposition of Trade Credit Mechanism

(a) Output Volatility					(b) Output Growth, 2009				
$\sigma, \%$		GE	PE	TC	$\Delta_{09}, \%$		GE	PE	TC
Y	PE_R	0.4271	0.4332	-1.41	Y	PE_R	-0.8798	-0.8952	-1.75
	PE_T	0.4271	0.4321	-1.18		PE_T	-0.8798	-0.8917	-1.35
Q	PE_R	0.3547	0.3486	+2.30	Q	PE_R	-0.7183	-0.7058	+1.74
	PE_T	0.3547	0.3595	-1.32		PE_T	-0.7183	-0.7291	-1.50

Note: This table presents the decomposition of (a) the volatility, σ , and (b) the drop in output during the 2008-2009 Financial Crisis, Δ_{09} , into general and partial equilibrium effects for aggregate output (Y) and of the mean response of sectoral output (q). The row (PE_R) reports the general equilibrium effect in column (GE) and the partial equilibrium effect from holding both interest rates on trade credit and trade credit shares constant (PE). Similarly, the row (PE_T) also reports the general equilibrium effect in column (GE) and the partial equilibrium effect from holding trade credit shares constant (PE). The column entries of (TC) are calculated as $(1-PE/GE)$ and therefore summarize the effect of the adjusting variable(s) on the general equilibrium. All numbers are reported in percent.

However, in case of aggregate output, the model predicts that the trade credit channel introduced in Section 3.2 reduces aggregate volatility by 1.41% and decreased the drop in GDP by 1.75%. The endogenous adjustment of the interest on trade credit led to a reduction in the volatility of output and the decline in output during the crisis by 1.18% and 1.35%, respectively. Consequently, the adjustment in the cost of trade credit contributed between 83% (1.18:1.41) and 77% (1.35:1.75) to the smoothing effect of the trade credit channel. The remaining 17-23% of the total effect can be attributed to changes in credit linkages. This result is complementary to the trade credit channel defined in 3.3, which highlights the propagation pattern of changes in credit costs and shares from the perspective of an individual firm. At the aggregate level, an increase in the interest rate on trade credit reduces the demand for trade credit and subsequently decreases the share of revenues extended on trade credit. The latter effect counteracts the increase in risk premia on bank credit due to the financial shock. Therefore, at the *aggregate* level, the overall ability of firms to adjust *both* its price of trade credit and its credit portfolio dampens the effect of shocks to the cost of bank credit.

(c) Credit Network and Shock Heterogeneity. In the last part of this quantitative exercise, I examine the role of heterogeneity of trade credit linkages and shocks on the trade credit multiplier defined in 4.2 by conducting two additional counterfactual exercises: (1) I first evaluate the importance of the asymmetry of credit linkages for the propagation of liquidity shocks by comparing the model's response against the response of an equivalent economy with symmetric trade credit shares in equilibrium. (2) The second counterfactual considers the role of asymmetric shocks by comparing the dynamics of the model when all sectors are affected by the same¹² shock to the cost of bank credit. Both exercises address the concerns raised in Section 4.2.1 regarding the disentanglement of the role of the trade credit mechanism from any effects induced by differences in the trade credit network or the size of shocks. The second and third row of Table 4.7 highlight that the implied trade credit multiplier is close to one which suggests that the asymmetry in both the credit link intensity and the financial shock only plays a minor role in the propagation of liquidity shocks.

(d) Heterogeneity in Net-Lending Position. As highlighted in Chapter 2, there is heterogeneity in the net-lending position of sectors defined as the ratio of accounts receivable to bank credit. Chapter 3 then introduced a model framework featuring endogenous trade credit linkages and costs which allowed to investigate the implications thereof for the propagation of financial shocks. In particular, Proposition 4 suggests that in an economy featuring both production and credit linkages, sectors who extend relatively

¹²The symmetric shock affecting all sectors equally is calculated as the average of sectoral shocks derived in Section 4.1.

more trade credit will generate more spillovers in the propagation of financial shocks. The intuition of this result is as follows: First, note that the interest rate of trade credit is more sensitive to financial shocks for sectors who extend relatively more trade credit to customers. Consequently, the amplification of the cost effect and therefore the reduction in output generated by an increase in the interest rate charged on trade credit will be more pronounced for sectors engaging more in inter-firm financial intermediation.

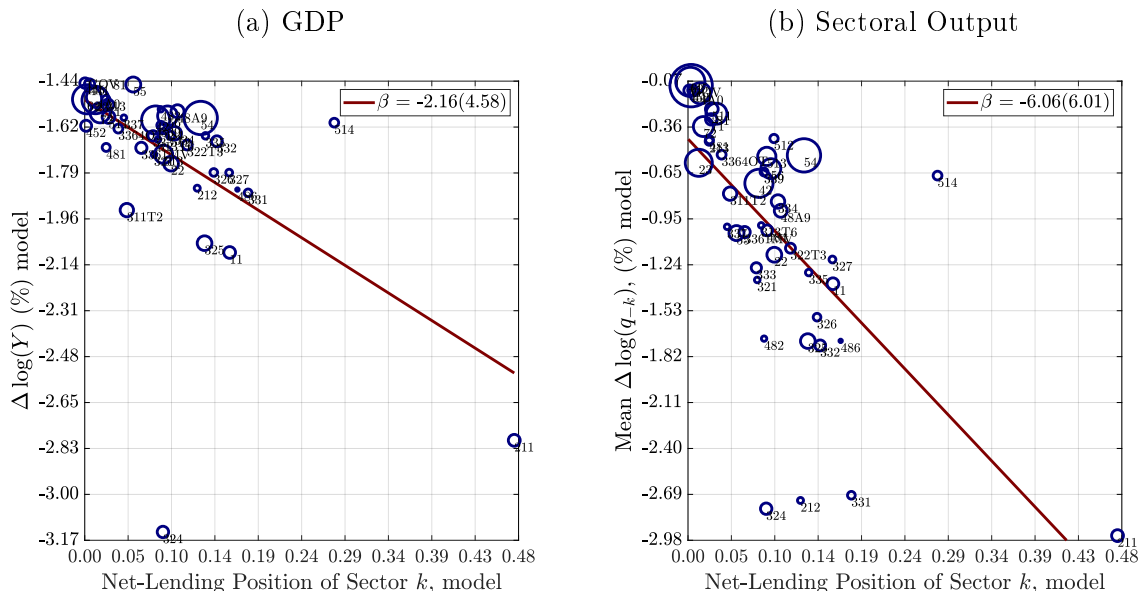
Taking the model to the data, the following exercise quantitatively evaluates the relevance of asymmetries in the trade credit usage of sectors for the propagation of liquidity shocks: For this purpose, I first identify the top five net-borrowers and the top five net-lenders based on the net-lending position (see Definition 2.1) of sectors calculated based on the mapping of the model to the data described in Section 4.1. This yields the following set of sectors: The sector IDs of the top net-lenders are $\{ 211, 514, 331, 486, 11 \}$ and the top net-borrowers $\{ 445, 452, 62, \text{GOV}, 441 \}$. Notably, as discussed in Chapter 2, the set of net-lenders is characterised by being more upstream in the supply chain of the US economy while the top net-borrowers are closer to the end consumer. I then feed in a symmetric shock series calculated as the average shock to sectoral risk premia that affects only one group of sectors at a time. The results of this exercise are reported in the last two rows of Table 4.7 and highlight that the aggregate trade credit multiplier is higher if sectors that extend relatively more trade credit than their upfront financing needs face an increase in their bank risk premium: Sectors which extend a lot of supplier credit in the US economy play a more central role in the propagation of liquidity shocks through inter-sectoral credit linkages relative to an economy with bank finance only.

This result relates to the predictions of Proposition 4 which I will now formally quantify: Consider the output response of those sectors, who were not directly affected by the same financial shock to the top five (a) net-lenders and (b) net-borrowers. The total effect of the trade credit channel - the endogenous adjustment of trade credit costs and shares - on output is measured by the difference between the general equilibrium and the partial equilibrium response of output, where the latter is obtained for the case in which both the interest rate on trade credit and the composition of the credit portfolio remain at their pre-crisis level. Due to the differences in the proximity of either group of sectors to the end consumer, I normalize the general and partial equilibrium responses of sectoral output by the log-change of aggregate labor in both exercises in order to control for equilibrium demand effects. While the average effect of trade credit on output is negative in both scenarios, a difference in means test confirms that the negative output effect of the sectoral trade credit channel generated by shocks to net-lenders is stronger and significantly differs from that generated by shocks to net-borrowers. This observation corroborates the predictions of Proposition 4: The adjustment of trade credit costs and credit shares in response to shocks to sectors classified as net-lenders will amplify the

negative effect of an increase in the bank rate affecting output of sector k .

While the previous exercise investigated the output response of sectors to the same financial shock to a selected group of sectors, I generalize this analysis by considering now a 10% increase in the shock to the bank risk premium of sector k for $k \in \{1, \dots, M\}$. The response of (a) real GDP and (b) the average sectoral output response of unaffected sectors normalized by the response of aggregate labor are then plotted against the net-lending position of the affected sector k in Figure 4.6. Figure 4.6 graphically depicts the quantitative implications of Proposition 4: The decline in (aggregate) output of unaffected sectors will be stronger in case of financial shocks affecting sectors who are relatively more engage in inter-firm financial intermediation.

Figure 4.6: Quantitative Illustration of Proposition 4

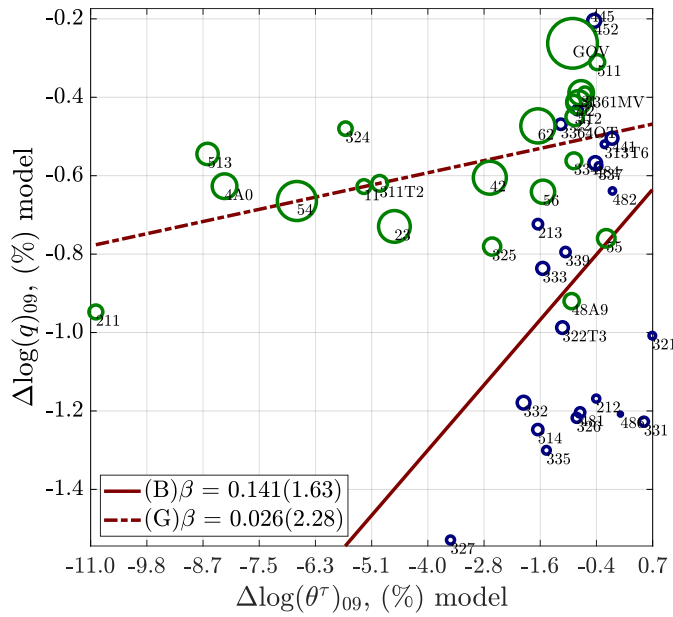


Note: This figure plots the response of (a) real GDP and of (b) average sectoral output of directly unaffected sectors ($-k$) to a 10% increase in the shock to the bank risk premium of sector k for $k \in \{1, \dots, M\}$ against the net-lending position of the affected sector k for $k \in \{1, \dots, M\}$. All response are normalized by the response of aggregate labor. The size of one observation represents the relative importance of the affected sector in the economy measured by the share of a sector's average pre-crisis (2004-2007) value added in total value added.

The discussion so far has focused on the total effect of the trade credit channel on aggregate and sectoral outcomes. However, an interesting question remains, whether sectors who experienced a stronger decline in trade credit during the crisis also exhibit a stronger decrease in output. In order to address this question, I conclude this section by plotting the log-change in sectoral output during the crisis in 2009 against the log-change of a sector's net-lending position during the crisis. The inspection of the correlation patterns presented in Figure 4.7 suggests that the model simulations reproduce the predictions of Chapter 2: Sectors who experienced a higher decrease in their net-lending position during the crisis also experienced a stronger decrease in output. A stronger decline in the net-lending position implies that a sector was more affected by decrease in the liquidity of the market for trade credit - either through a decrease in trade credit extended to cus-

tomers or trade credit obtained from supplier or both. This positive correlation is more pronounced for sectors with a relative higher share of intermediate inputs in production.

Figure 4.7: Model-Implied Change in Trade Credit and Output Growth in 2009



Note: This figure plots the log-change in sectoral output during the crisis in 2009 against the log-change of a sector's net-lending position (θ_k^τ) during the crisis implied by the model-simulations. The sectors are split according to the median value added share. The value added share is defined as the share of sector k 's value added in total value added and is calculated using the four-year (2004-2007) pre-crisis values observed in the data. The same measure is used to represent the size of a sector in this figure. The set of sectors with a value added share below the median are represented using blue dots (B), while those with a value added share above the median are represented by green dots (G).

Table 4.7: Trade Credit Multipliers of Counterfactual Simulations

	CF	EN	Aggregate				Sectors		
			(1)	(2)	(3)	(4)	(5)	(6)	(7)
			$\Delta\%(Y)_{09}$	$\Delta\%(L)_{09}$	$\Delta\%(\Phi^Z)_{09}$	$\Delta\%(\Phi^L)_{09}$	$\Delta\%(q)_{09}$	$\Delta\%(\ell)_{09}$	$\Delta\%(\phi^V)_{09}$
(a)	TC0	$\mathcal{E}(\theta)$	-0.880	-0.548	-0.525	-0.037	-0.718	-0.786	0.556
		$\mathcal{E}(0)$	-0.457	-0.336	-0.239	-0.105	-0.172	-0.373	0.174
		\mathcal{M}	1.926	1.632	2.196	0.355	4.185	2.105	3.200
(c)	TCA	$\mathcal{E}(\theta)$	-0.880	-0.548	-0.525	-0.037	-0.718	-0.786	0.556
		$\mathcal{E}(\bar{\theta})$	-0.877	-0.551	-0.521	-0.043	-0.705	-0.803	0.542
		\mathcal{M}	1.003	0.995	1.008	0.854	1.019	0.979	1.027
(c)	TCS	$\mathcal{E}(\theta)$	-0.880	-0.548	-0.525	-0.037	-0.718	-0.786	0.556
		$\mathcal{E}(\bar{z})$	-0.883	-0.532	-0.539	-0.008	-0.736	-0.726	0.514
		\mathcal{M}	0.996	1.030	0.974	4.635	0.976	1.083	1.083
(d)	NL	$\mathcal{E}(\theta)$	-0.045	-0.022	-0.031	0.008	-0.096	-0.093	0.068
		$\mathcal{E}(0)$	-0.010	-0.007	-0.005	-0.003	-0.013	-0.046	0.012
		\mathcal{M}	4.695	3.030	6.318	-2.871	7.352	2.040	5.825
(d)	NB	$\mathcal{E}(\theta)$	-0.236	-0.162	-0.131	-0.034	-0.046	-0.077	0.049
		$\mathcal{E}(0)$	-0.170	-0.127	-0.088	-0.042	-0.015	-0.030	0.030
		\mathcal{M}	1.386	1.276	1.491	0.818	3.069	2.605	1.659

Note: This table documents the model simulated log-change of the following variables to shocks to sector-specific bank risk premia in an economy with bank and supplier credit, $\mathcal{E}(\theta)$, an equivalent economy with bank credit only, $\mathcal{E}(0)$, with symmetric trade credit shares (TCA), $\mathcal{E}(\bar{\theta})$, and an economy featuring symmetric shocks (TCS), $\mathcal{E}(\bar{z})$: aggregate output (Y), labor (L), the aggregate efficiency (Φ_ϕ^Z) and labor wedge (Φ_ϕ^L), the average sectoral output (q), labor (ℓ) and credit cost wedge (ϕ^V). The trade credit multipliers (\mathcal{M}) are calculated as the ratio of responses of the variable in $\mathcal{E}(\theta)$ to their counterparts in $\mathcal{E}(0)$, $\mathcal{E}(\bar{\theta})$ and $\mathcal{E}(\bar{z})$, respectively. The equivalent economies of the five counterfactual exercises considered are an economy with bank finance only (TC0); with symmetric trade credit shares (TCA); symmetric shocks (TCS); (NL/NB) in which only net-lenders (net-borrowers) experience an increase in their bank interest rates using Definition 2.1. All log-changes are reported in percent.

4.3 Concluding Remarks

Empirical and anecdotal evidence in the literature shows that trade credit in the form of delayed input payments plays a central role in day-to-day business operations and generates further interdependencies between firms, beyond the pure exchange of goods and services. During the 2008-2009 Financial Crisis the market for trade credit contracted sharply as documented in previous work by Costello (2017). Chapter 2 presented facts on correlations patterns between the trade credit usage of US firms and macroeconomic dynamics. It is shown that trade credit comoves strongly with GDP and was severely affected at the onset of the 2008-2009 Financial Crisis, as captured by the compositional shift of short-term borrowing towards bank credit. Furthermore, firms differ in their usage of trade credit and tend to extend less trade credit to customers than their own cost of production. The investigation of simple correlation patterns suggests that sectors who were more exposed to suppliers engaging relatively more in inter-firm financial intermediation, also experienced a sharper drop in output during the crisis. Motivated by these observations, this thesis studied the role of endogenous trade credit linkages in an inter-sectoral production network for the propagation of liquidity shocks.

In particular the research objectives and contributions to the literature of this thesis are twofold: (1) To build a model that captures the features of trade credit as a smoothing and as an amplification device and subsequently allows to study the implications of interdependent distortions for the propagation of financial shocks. (2) To quantitatively assess the role of trade credit for the propagation of financial shocks relative to an economy with bank finance only on the one hand, and the relative strength of the trade credit mechanism for economic outcomes on the other.

For this purpose, Chapter 3 introduced a static quantitative multisector model in which firms finance their working capital requirements using both bank and supplier credit. Profit-maximizing firms (a) choose the composition of their borrowing portfolio to minimize their cost of production and (b) optimally set both the price of the good and the interest rate on trade credit. The model introduces the two features of trade credit as follows: On the one hand, the existence of two external financing sources allows firms to smooth any interest rate shocks via an adjustment of their borrowing portfolio by optimally trading-off credit costs. On the other hand, an increase in the external financing conditions of a firm directly translates into an increase in the cost of trade credit, thereby tightening the financing terms for its customers. It is shown that the net-lending position of a firm, capturing the extent to which firms are involved in inter-firm financial intermediation relative to their own credit needs, determines its systemic importance in the transmission of liquidity shocks. In a quantitative application of my model to the US economy during the crisis, simulations featuring only financial shocks show that the model

captures approximately a third of the drop in output, half of which can be attributed to the existence of trade credit linkages alone. This suggests that relative to an economy with bank finance only, the introduction of trade credit linkages generate considerable spillovers. A complementary exercise investigates the effect of the trade credit channel - the endogenous adjustment of trade credit cost and shares - on aggregate volatility. While the ability of firms to adjust their borrowing portfolio overall decreases aggregate volatility by 1.4%, the effect is rather small but implies that the smoothing mechanism of trade credit was operative. In a last application, I confirm the predictions derived in the theoretical section of this thesis on the relevance of the net-lending position of a firm for aggregate fluctuations: A financial shock to a sector extending more supplier credit relative to its upfront working capital requirements implies that the amplification mechanism of trade credit is more pronounced relative to a bank finance only economy.

Overall, this thesis contributes to the literature by emphasising interdependent and endogenous distortions and their implications for macroeconomic outcomes. While other sources of interdependencies such as production linkages have been more extensively investigated in the literature, this thesis has focused on the role of financial linkages between firms and analysed their quantitative relevance for the macroeconomy. As the literature on the macroeconomic implications of inter-firm credit networks and interdependent distortions is a growing field, this thesis also suggests interesting paths for future research. In particular, even though this thesis features endogenous credit linkages, firms are only able to adjust their credit links along the intensive margin rather than the extensive margin.

A new growing literature investigates the endogenous link formation between economic agents (see [Oberfeld, 2018](#)) and is therefore an appealing concept and line of research as trade credit is also used by firms to build up their customer base and attract new customers. (see [Gourio and Rudanko, 2014](#); [Giannetti et al., 2018](#)) In other words, rather than taking the existence of financial linkages among firms as given, the ability of firms to access other credit markets and obtain trade credit can affect the formation of customer-supplier relationship between firms. (see e.g. [Giovannetti, 2016](#)) Based on the observations presented in Chapter 2, the relationship between trade credit and other credit markets such as bank credit and the implications of their joint existence for the transmission of monetary policy shocks is another interesting line for future research (e.g. [Nilsen, 2002](#); [Mateut et al., 2006](#)). To conclude, this thesis emphasises the importance of trade credit as a transmission mechanism of financial shocks and for macroeconomic fluctuations and proposes new paths for future research exploring firms as liquidity providers in an economy.

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A. Matrix and Variable Notation

In this appendix, I first provide an overview of the matrix notation and operations as well as graph theoretical concepts applied in this thesis.

Matrix and Variable Notation. Matrices are denoted as bold capital letters (e.g. \mathbf{X}) and vectors as bold small letters (e.g. \mathbf{x}). Since the economy consists of M sectors, matrices in the following are of size $[M \times M]$ and vectors are of size $[M \times 1]$, unless otherwise stated.

Auxiliary Matrix Operations		
$\text{inv}(\cdot)$...	inverse of a matrix
$\text{diag}(\cdot)$...	extracts diagonal entries of matrix \mathbf{X} ; generates diagonal matrix using vector \mathbf{x}
$\text{vec}(\cdot)$...	vectorizes matrix \mathbf{X} by stacking each column
\circ	...	denotes the Hadamard product
\otimes	...	denotes the Kronecker product
$\mathbf{1}$...	vector of ones
\mathbf{J}	...	$= \mathbf{1}\mathbf{1}'$.

Production and Credit Network. The matrices $\mathbf{\Omega}^X$ and $\mathbf{\Theta}$ denote the intermediate production structure and credit network, respectively. To simplify notation let $\mathbf{\Omega} = \mathbf{\Omega}^X$ below. Both the production and credit network can be mapped into standard graph theoretical notation. Following [Carvalho \(2010\)](#), define the set of M sectors as the vertex set $\mathcal{V} = \{v_1, \dots, v_M\}$ and let $\mathcal{E}(\mathbf{\Omega})$ and $\mathcal{E}(\mathbf{\Theta})$ be subsets of all ordered pairs of vertices $\{v_k, v_s\}$, with $v_k, v_s \in \mathcal{V}$ defined as

$$\mathcal{E}(\mathbf{\Omega}) = \{\{v_k, v_s\} \in \mathcal{V}^2 : \{v_k, v_s\} \in \mathcal{E}(\mathbf{\Omega}) \text{ if Sector } s \text{ supplies inputs to Sector } k\} \quad (\text{A.1a})$$

$$\mathcal{E}(\mathbf{\Theta}) = \{\{v_k, v_s\} \in \mathcal{V}^2 : \{v_k, v_s\} \in \mathcal{E}(\mathbf{\Theta}) \text{ if Sector } s \text{ extends credit to Sector } k\} \quad (\text{A.1b})$$

Therefore, the Cobb-Douglas technology implies that the entry $[\mathbf{\Omega}]_{ks} = \omega_{ks}$ denotes the share of good s in the total intermediate input use of sector k and it is assumed that $\sum_{s=1}^M \omega_{ks}^X = 1 \forall k \in \{1, \dots, M\}$. The production parameters are fixed and calibrated using the IO-Tables provided by the BEA as described in [Section 4.1](#). Similarly, $[\mathbf{\Theta}]_{ks} = \theta_{ks}$ denotes the share of intermediate good expenditures of sector k obtained on trade

credit from supplier s , which is endogenously determined in the model. Due to the complementarity of the production and the credit network, it follows that $\mathcal{E}(\Theta) \subseteq \mathcal{E}(\Omega)$. In other words, a credit link between sector k and s only exists if both sectors also engage in input trade. The production as well as the credit network can be described as directed graphs $G(\Omega)$ and $G(\Theta)$ applying Definition 1 in [Carvalho \(2010\)](#)

Definition A.1. $G(\Omega) = G(\mathcal{V}, \mathcal{E}(\Omega))$ is a directed sectoral trade linkages graph with vertex set \mathcal{V} and edge set $\mathcal{E}(\Omega)$, where each element of $\mathcal{E}(\Omega)$ is a directed arc from element i to j . Similarly, $G(\Theta) = G(\mathcal{V}, \mathcal{E}(\Theta))$ defines the credit linkages graph.

Standard network descriptive statistics defined below (see e.g. [Jackson, 2008](#); [Carvalho, 2010](#)) are used to characterize the production and credit network in Chapter 4. Let $\mathcal{N} \in \{\Omega, \Theta\}$ and define the adjacency matrix of \mathcal{N} as $\mathbf{A}_{\mathcal{N}}$. The in- and out-degree of sectors measure the heterogeneity of sectors along the extensive margins of input(credit) demand and input(credit) supply.

Definition A.2. The in-degree, $d_k^I(\mathcal{N})$, of a vertex $v_k \in \mathcal{V}$ is defined as the cardinality of the set $\{v_s : v_s \rightarrow v_k\}$. The out-degree, $d_k^O(\mathcal{N})$, of a vertex $v_k \in \mathcal{V}$ is defined as the cardinality of the set $\{v_c : v_k \rightarrow v_c\}$.

In other words, the in(out)-degree is calculated as the number of all non-zero entries in the respective row(column) of matrix \mathcal{N} and represent the number of suppliers(customers) of sector k . Due to the complementarity of the trade and the credit network, the in- and out-degree of either network as defined above will exhibit an almost positive perfect correlation. Therefore, I also calculate the weighted in- and out-degree as follows

Definition A.3. The weighted in-degree, $d_k^I(\mathcal{N})$, of a vertex $v_k \in \mathcal{V}$ is defined as the row sum of \mathcal{N} divided by the in-degree of v_k . The weighted out-degree, $d_k^O(\mathcal{N})$, of a vertex $v_k \in \mathcal{V}$ is defined as the column sum of \mathcal{N} divided by the out-degree of v_k .

In other words, the weighted in-degree equals a sector's average input- and credit-demand-share, respectively, and the weighted out-degree represents the average sales- and credit-supply-share. The last network measure applied in this thesis is the weighted Bonacich centrality, which describes the systemic importance of a sector based on the total weighted number of walks between two sectors and is similar to the concept of the Leontief-Inverse common to any input-output model.

Definition A.4. The Demand and Supply Bonacich-Centrality vector is defined as

$$b^d(\mathcal{N}) = (\mathbf{I} - \tilde{\mathcal{N}})^{-1} \cdot \boldsymbol{\iota} \quad \text{and} \quad b^s(\mathcal{N}) = [(\mathbf{I} - \tilde{\mathcal{N}})^{-1}]' \cdot \boldsymbol{\iota} \quad (\text{A.2})$$

where $\tilde{\mathcal{N}} = \text{diag}(\mathbf{n}(\mathcal{N}))\mathcal{N}$ are the normalized production and credit networks, with $\mathbf{n}(\Omega) = \text{diag}(\boldsymbol{\eta})$ and $\mathbf{n}(\Theta) = (\boldsymbol{\iota}'\Theta\boldsymbol{\iota})^{-1}\boldsymbol{\iota}$.

B. Appendix to Chapter 2

In this appendix, I describe the data sources and variables used to derive the results in Chapter 2 and to calibrate the model presented in Chapter 3.

B.1 Data Sources and Sample Description

GDP and Sectoral Output. Data on nominal and real aggregate US GDP, aggregate Imports and Exports, Gross Output and the corresponding GDP-Deflator are obtained from the [Bureau of Economic Analysis \(BEA\)](#). Sectoral data are obtained from the summary tables on "Use of Commodities by Industries After Redefinitions" provided by the BEA.

Prices and Wages. Data on total hours worked and sectoral prices are obtained from the Bureau of Labor Statistics ([BLS](#)). In particular, I combine the respective variables from the MFP- and the LPC-Database in order to deal with missing data when required.

Lending Standards. The [Senior Loan Officer Opinion Survey on Bank Lending Practices](#) - conducted by the Federal Reserve - reports the tightening in lending standards (LS) by banking institutions defined as the net percentage of domestic respondents tightening their standards for commercial and industrial (C&I) loans.

Sectoral Credit Spreads and Federal Funds Rate. The sectoral credit spreads (r_{kt}^Z) are derived in [Gilchrist and Zakrajšek \(2012\)](#) and provided to me by the authors. The federal funds rate (x_{0t}^B) is obtained from the [FRED, Federal Reserve Bank of St. Louis](#) database.

Balance Sheet and Income Statement Data of US Firms. The [Compustat](#) database is used to infer sectoral trade credit (shares) based on the balance sheet data on accounts receivable and payable of US firms. A firm is included in the sample if all of the following criteria hold

- (1) non-missing NAICS-classification
- (2) headquarter in the US
- (3) non-missing and non-negative data on balance sheet and income statement items^(a)

- (4) accounts receivable do not exceed sales
- (5) accounts payable and the sum of accounts payable and cash do not exceed total production costs
- (6) non-missing consecutive observations over the time period 2005-2010

Furthermore, firms are excluded who either enter or exit the Compustat database during the period 2005-2010. In total, 2,686 firms are included in the initial sample per year on average. The average number of firms in each sector and the representativeness of the firms for each industry are presented in Table B.1 across all years 1997-2016. The reduced sample used to construct Figure 2.1 and 2.2 only contains firms with non-missing values over the sample period 1997-2016. Furthermore, in order to align financial and macroeconomic variables, a firm's observation is assigned to the previous calendar year if its fiscal year ends in the months January through May and assigned to the current calendar year if its fiscal year ends in the months June through December.

(a) The following balance sheet and income statement items^(a) are obtained to construct the variables discussed in Section 2.1 and to calibrate the model as shown in Section 4.1. A short description based on the definition given in the Compustat database is included.

- *Accounts Payable (ap)* are trade obligations due within one year and are included in current liabilities (*lc*).
- *Accounts Receivable (ar)* represent amounts on open account owed by customers for goods and services sold.
- *Cost of Goods Sold (cogs)* are all expenses directly related to the production of goods and services sold to customers.
- *Total Sales (R)* represent all realised revenues during the fiscal period.
- *Total Assets (at)* of a company.
- *Total (lt) and Current Liabilities (lc)*. Total Liabilities (*lt*) are the sum of current liabilities (*lc*), long-term debt and other non-current liabilities. Current Liabilities include debt in current liabilities (*dlt*), accounts payable (*AP*) and other liabilities due within one year.
- *Total Long-Term (dlt) and Current Debt (dlc)*. Long-Term Debt (*dlt*) is defined as all debt obligations due in more than one year. Current Debt (*dlc*) denotes all interest-bearing obligations due after the current year including long-term debt due in one year and short-term borrowings/notes payable (*np*).

(b) In addition, the following variables are obtained:

- *Interest Expenditures* ($xint$) of the company of securing short- and long-term debt.
- *(Cash) Dividends* (dv) representing the total amount of cash dividends paid for capital.
- *Net Income* (ni) defined as the fiscal period income or loss after subtracting expenses and losses from all revenues and gains.
- *Interest Income* ($idit$) defined as revenues received from interest-bearing obligations held by the company.
- *Depreciation* (dp) associated with spreading the actual cost of tangible capital assets over their useful life.
- *Cash* (ch) holdings of a company.
- *Notes Payable* (np) denoting the total amount of short-term notes including i.a. bank acceptances and overdraft, commercial paper.
- *R&D Expenditures* (xrd) associated with the development of new products or services.

Any missing values are assigned the value of zero and a firm-year observation is excluded if the sum of net income (ni), dividends (dv) and interest expenditures ($xint$) is zero. The composition and representativeness of both samples of US firms obtained from Compustat - (a) restricted and (b) unrestricted with respect to the time coverage and missing values of firms - is presented in Table B.1 at a sector level. The less restrictive sample (b) is used to calibrate the sector-to-sector equilibrium trade credit shares in model as described in Section 4.1.

Table B.1: Sample Description

ID	Sector	Description	(a) Stylised Facts			(b) Calibration			NL
			#Firms	RP(Y)	RP(R))	#Firms	RP(Y)	RP(R))	
1	11	Agriculture	4	0.03	0.01	13	0.15	0.06	0.17
2	211	Oil and Gas	6	0.88	0.55	57	1.88	1.13	0.57
3	212	Mining, except 211	7	0.54	0.27	26	1.03	0.52	0.10
4	213	Support for 212	6	0.68	0.51	20	0.82	0.60	0.03
5	22	Utilities	55	0.81	0.48	175	2.47	1.47	0.11
6	23	Construction	11	0.06	0.04	30	0.08	0.04	0.01
7	311T2	Food, Beverages and Tobacco	38	1.04	0.29	92	1.63	0.45	0.04
8	313T6	Textile, Apparel and Leather	24	1.94	0.61	69	3.04	0.95	0.08
9	321	Wood Products	6	0.22	0.06	14	0.48	0.14	0.07
10	322T3	Paper Products and Printing	18	0.85	0.31	46	1.30	0.48	0.11
11	324	Petroleum and Coal Products	8	4.52	1.17	21	6.22	1.63	0.06
12	325	Chemical Products	52	1.10	0.45	185	1.72	0.70	0.13
13	326	Plastics and Rubber Products	12	0.50	0.17	33	0.73	0.24	0.14
14	327	Nonmetallic Mineral Products	9	0.43	0.18	21	0.61	0.25	0.15
15	331	Primary Metals	19	1.15	0.28	40	1.66	0.42	0.16
16	332	Fabricated Metal Products	27	0.42	0.17	59	0.61	0.25	0.15
17	333	Machinery	51	1.05	0.38	131	1.50	0.55	0.07
18	334	Computer and electronic Products	65	1.13	0.62	274	2.42	1.34	0.10
19	335	Electrical Equipment and Components	19	0.41	0.17	49	1.16	0.48	0.13
20	3361MV	Motor Vehicles, Bodies and Parts	23	0.46	0.10	52	0.98	0.23	0.06
21	3364OT	Other Transportation Equipment	18	2.42	0.97	34	2.99	1.20	0.04
22	337	Furniture and Related Products	12	0.47	0.18	24	0.82	0.31	0.04
23	339	Misc Manufacturing	17	0.48	0.23	81	0.79	0.38	0.09
24	42	Wholesale Trade	56	0.41	0.29	145	0.76	0.53	0.06
25	441	Motor Vehicle and Parts Dealers	7	0.30	0.21	17	0.76	0.53	0.01
26	445	Food and Beverage Stores	6	0.93	0.64	16	1.53	1.06	0.00
27	452	General Merchandise Stores	11	4.63	3.15	22	5.11	3.49	0.00
28	4A0	Other Retail	6	1.63	0.76	19	2.24	1.04	0.01
29	481	Air Transport	6	2.09	1.13	8	2.31	1.25	0.02
30	482	Rail Transport	14	0.23	0.10	25	0.30	0.14	0.07
31	484	Truck Transport	4	1.28	0.83	26	6.13	3.67	0.07
32	486	Pipeline Transport	5	0.83	0.41	26	0.88	0.46	0.19
33	48A9	Other Transport and Warehousing	41	0.85	0.54	135	1.31	0.84	0.10
34	511	Publishing Industries	5	0.03	0.02	71	0.23	0.13	0.04
35	512	Motion Picture and Sound	1	0.37	0.22	13	0.52	0.31	0.13
36	513	Broadcasting & Telecommunications	13	0.53	0.27	93	1.55	0.79	0.10
37	514	Information Services	4	1.77	0.99	59	2.33	1.28	0.22
38	54	Professional & Technical Services	20	0.04	0.02	135	0.10	0.06	0.17
39	55	Management of Companies	-	-	-	-	-	-	0.00
40	56	Administrative & Waste services	31	0.17	0.11	85	0.27	0.17	0.10
41	62	Health Care & Social Assistance	21	0.10	0.08	83	0.17	0.13	0.00
42	71	Arts, Entertainment, Recreation	8	0.04	0.02	32	0.13	0.08	0.02
43	72	Accommodation & Food Services	20	0.19	0.10	79	0.30	0.17	0.01
44	81	Other Services except GOV	5	0.01	0.01	14	0.02	0.01	0.04
45	GOV	Government and Education	5	0.01	0.04	37	0.01	0.09	0.00
Mean			18	0.86	0.41	61	1.41	0.68	0.09
Stdv			16	1.01	0.53	56	1.47	0.78	0.09
Min			1	0.01	0.01	8	0.01	0.01	0.00
ID			(35)	(44)	(44)	(29)	(45)	(44)	(39)
Max			65	4.63	3.15	274	6.22	3.67	0.57
ID			(18)	(27)	(27)	(18)	(11)	(31)	(2)

Note: This table presents the NAICS (2007) IDs and descriptions of the sectors included in the calibration of the model. In addition, the table reports the average number of firms (#Firms) in each industry included in the sample from Compustat over the entire sample period 1997-2016 used (a) to calculate aggregate statistics for the respective financial variables presented in Figure 2.1 Section 2.1 and (b) in the calibration of the model discussed in Section 4.1. The representativeness of the sample for each sector is calculated as the share of total sales of firms in industry value added (RP(Y)) and in gross industry output (RP(R)) as reported by the BEA. The last column reports the average net-lending position of each sector based on Definition 2.1.

B.2 Variable Description

In the following, I provide a description of the variables included in the regressions presented in Table 2.2 in Section 2.1. Sectoral aggregates are obtained by summing the respective balance sheet item or income variable over all firms assigned to the sector in a given year. The variables are calculated as follows

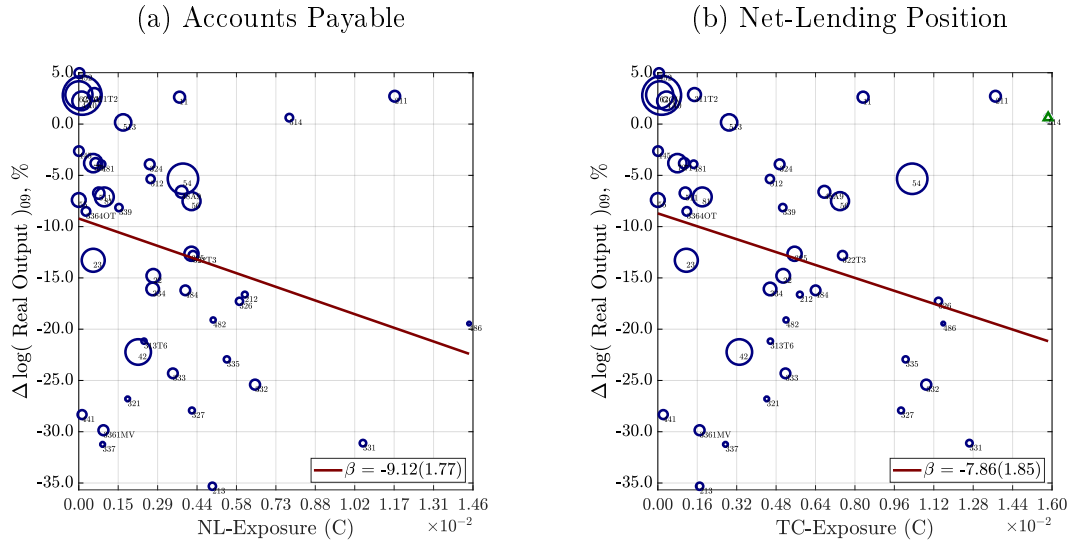
- *Trade Credit Shares.* The variable θ_{kt}^P defines share of accounts payable (*ap*) in total cost of production (*cogs*) and θ_{kt}^R denotes the share of accounts receivable (*ar*) in total sales (*sales*).
- *Financial Shares.* The variable θ_{kt}^F is calculated as the ratio of current (*dlt*) to long term debt (*dlt*). The share of cash (*ch*) in total production cost (*cogs*) is denoted by θ_{kt}^E .
- *Size.* The relative size of a sector is measured by the share of a sector's assets (*at*) in total assets in the economy.
- *Leverage.* The leverage ratio (LV_{kt}^S) is calculated as the share of total debt (*dlt* + *dlt*) in sales (*R*). Note that I use sales in the denominator rather than total assets (*at*) as accounts receivable are also included as a share of total sales.
- *Detrended Cost of Production* (C_{kt}^X) are obtained by detrending total sectoral cost of production (*cogs*) using an hp-filter with a smoothing constant of 6.25 as suggested for annual data by Ravn and Uhlig (2002).
- *Exposure to Trade Credit.* Similar to Equation (2.2) in the main text, Equation (B.1) denotes the weighted average of sector *k*'s customers accounts payable shares:

$$e_k^P = \sum_{m=1, m \neq k}^M w_{km}^P \frac{ap_m}{cogs_m} \text{ where } w_{km}^P = \frac{ar_k}{R_k} \left(\frac{p_k x_{mk}}{R_k} \right). \quad (\text{B.1})$$

From the perspective of sector *k*, the exposure measure presented in Equation (B.1) is calculated as the weighted sum of its customers' share of accounts payable in total cost of production. Similar to the exposure measure to *k*'s suppliers, the accounts payable shares capture the extend to which customers of sector *k* rely on trade credit and are therefore more exposed to changes in the cost and supply of trade credit. The weights (w_{km}^P) are a combination of sector *k*'s share of revenues generated by selling its output to sector *m* and sector *k*'s overall share of revenues extended on trade credit to customers. The weights capture the importance of sector *m* as a customer of sector *k*. Figure B.1 plots sectoral output growth during the crisis against the four-year (2004-2007) pre-crisis average of the

each sector's exposure to trade credit obtained by its customers. The correlation patterns shown in Figure B.1 suggest that sectors who are more exposed to customers with a larger accounts payable share in their production costs exhibit a larger *decrease in output* after the shock. A similar pattern is observed for the exposure to the net-lending position of customers.

Figure B.1: Output Growth and Exposure to Trade Credit of Customers



Note: This figure plots sectoral output growth in 2009 against a sector's average pre-crisis (2004-2007) exposure to (a) the accounts payable shares of its customers (e_k^P) defined in Equation (B.1) and (b) the net-lending position of its customers. The fitted line of an OLS-regression and corresponding coefficient and T-statistic are also reported. If applicable, outliers excluded from the regression are represented by a green triangle. The size of one observation represents the relative importance of the sector in the economy measured by the share of a sector's average pre-crisis (2004-2007) value added in total value added.

C. Appendix to Chapter 3: Model-Derivations

This appendix discusses the derivation of the first order conditions of the model introduced in Chapter 3 and contains the proofs of the respective lemmata. Appendix C.1 discusses the properties of the interest rate on bank credit and the credit management cost function. Appendix C.2 presents the household's utility maximization problem and Appendix C.3 discusses the profit maximization problem of the final and intermediate good producing firm. A summary of the equilibrium condition of the model is presented in Appendix C.5. Appendix C.4 provides the proofs to the lemmata introduced in Section 3.2.1.

C.1 Credit Costs

Interest Rate on Bank Credit. As proposed in the main text, the interest rate on bank credit is assumed to take on the following functional form:

$$r_k^B = r_0^B + r_k^Z = (1 + A_k^B(\theta_k^Z)^\mu) r_0^B, \text{ where } \theta_k^Z = \bar{\theta}_0^D + \theta_k^C.$$

In other words, sector k is charged a mark-up over the federal funds rate when obtaining bank credit. This mark-up - or risk premium - is subject to sector-specific shocks, $A_k^B = \exp(z_k^b)$, and is increasing and convex in the share of accounts receivable, $\sum_{c=1}^M \theta_{ck} p_k x_{ck}$, in net sales $p_k q_k$, (θ_k^C) . It holds that

$$0 < \frac{\partial r_k^B}{\partial \theta_k^C} = \mu \frac{r_k^Z}{\theta_k^Z}, \quad \frac{\partial^2 r_k^B}{\partial (\theta_k^C)^2} = \mu(\mu - 1) \frac{r_k^Z}{(\theta_k^Z)^2},$$

The convexity of r_k^B in θ_k^C follows from the assumption that $\mu > 1$.

Credit Management Costs. C_k^T denotes the combination of linear and quadratic adjustment costs and is defined as

$$C_k^T(\{\theta_{ks}\}_s) = w\ell_k^T = \kappa_k^B + \sum_{s=1}^M \kappa_{0,ks}^T \theta_{ks} + \frac{\kappa_{1,ks}^T}{2} \left(\frac{\theta_{ks} - \bar{\theta}_k^S}{\bar{\theta}_k^S} \right)^2$$

The credit management costs are increasing and convex in θ_{ks}

$$0 < \frac{\partial w\ell_k^T}{\partial \theta_{ks}} = +\kappa_{0,ks}^T - \frac{\kappa_{1,ks}^T}{\bar{\theta}_k^S} + \frac{\kappa_{1,ks}^T}{(\bar{\theta}_k^S)^2} \theta_{ks}, \quad \frac{\partial^2 w\ell_k^T}{\partial (\theta_{ks})^2} = \frac{\kappa_{1,ks}^T}{(\bar{\theta}_k^S)^2}$$

which follows from $0 < \kappa_{1,ks}^T \forall k, s$.

C.2 The Household's Optimization Problem

A representative household maximises expected life-time utility

$$\max_{C,L} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t U(C, L)(t) \quad (\text{C.1})$$

subject to the period-by-period budget constraint

$$P(t)C(t) = w(t)L(t) + \Pi(t) + T(t) \quad (\text{C.2})$$

The representative household owns all firms, such that in addition to total labor income, wL , she receives total profits (dividends) of firms, $\Pi = \sum_{m=0}^M \pi_m$. If the household also owns the financial sector, she will receive the interest payments on bank credit in the form of additional transfers, $T(t)$, which will be further discussed in Section D.1. As there is no uncertainty in the model and the household does not face an intertemporal decision, I can drop both the expectations operator as well as the time subscript for notational convenience. Let the utility function be given by Equation (C.3) such that the FOCs implies the optimal consumption-labor choice in Equation (C.4).

$$U(C, L) = \frac{C^{1-\epsilon_C}}{1-\epsilon_C} - \frac{L^{1+\epsilon_L}}{1+\epsilon_L}. \quad (\text{C.3}) \quad \text{and} \quad \frac{L^{\epsilon_L}}{C^{-\epsilon_C}} = \frac{w}{P} \quad (\text{C.4})$$

C.3 The Firms' Optimization Problem

Both intermediate and final goods are produced by a representative, price-taking firm in the respective sector. While final good producing firms only face their profit maximization problem, the intermediate good producing firm faces two maximisation problems each period: (1) Profit Maximization Problem, and (2) Credit Decision Problem. Sections C.3.1 and C.3.2 derive and discuss the profit maximization problem of the final and intermediate good firm, respectively. The credit decision problem of a representative intermediate good producing firm is discussed separately in Appendix C.3.3.

C.3.1 Final Good Producer's Optimal Input Decisions

Final good producing firms operate in a perfectly competitive market and do not face any working capital constraints. The representative firm's dual problem is to (1) choose the optimal amount of the sectoral inputs $\{x_{0m}\}_m$ to *minimize the cost* of producing $F = 1$ and (2) *maximize profits* by choosing the optimal amount F produced. (1) First, let $\mathcal{P}F$ denote the cost-minimizing expenditures on inputs of the final good producing firm solving

$$\mathcal{P}F \equiv \min_{\mathcal{V}_0} \sum_{m=1}^M p_m x_{0m} \quad \text{subject to} \quad F = A_0 \prod_{m=1}^M x_{0m}^{\omega_m^F}$$

where \mathcal{P} is the price index of the input composite, $\mathcal{V}_0 = \{x_{0m}\}_{m=1}^M$ denotes the set of choice variables and $A_0 = \exp(z_0^q) \bar{A}_0$, as outlined in the main text. The normalization constant is defined as $[\bar{A}_0]^{-1} = \prod_{m=1}^M (\omega_m^F)^{\omega_m^F}$ and the productivity shock z_0^q is normally distributed as $\mathcal{N}(0, \sigma_{q,0}^2)$ such that $A_0 = \bar{A}_0$ in equilibrium. The FOCs of the cost-minimization problem imply that $\mathcal{P} = \prod_{m=1}^M p_m^{\omega_m^F}$. (2) The FOCs of the final good producing firm's profit maximization problem yield $P = \mathcal{P}$. The optimal final demand for sector m 's output is therefore given by Equation (C.5) and the optimal price charged for the final good is shown in Equation (C.6).

$$x_{0m} = \omega_m^F \left(\frac{p_m}{P} \right)^{-1} F \quad (\text{C.5}) \quad \text{and} \quad P = \prod_{m=1}^M (p_m)^{\omega_m^F}. \quad (\text{C.6})$$

C.3.2 Intermediate Good Producer's Optimal Input Decisions

Intermediate Production Technology. The production function (3.1) is given by

$$q_k = \left(\exp(z_k^q) \bar{A}_k^Q k_k^{\alpha_k \eta_k} V_k^{1-\alpha_k \eta_k} \right)^{\chi_k}. \quad (\text{C.7})$$

The composite of (productive) labor and intermediate inputs, V_k , as well as the composite of intermediate inputs, X_k are defined as

$$V_k = \bar{A}_k^V \left(\ell_k^Q \right)^{v_k} \left(X_k \right)^{1-v_k} \quad \text{and} \quad X_k = \bar{A}_k^X \prod_{s=1}^M x_{ks}^{\omega_{ks}^X} \quad (\text{C.8})$$

where

$$v_k = \frac{(1 - \alpha_k) \eta_k}{1 - \alpha_k \eta_k} \quad \text{and} \quad 1 - v_k = \frac{(1 - \eta_k)}{1 - \alpha_k \eta_k}$$

such that both V_k and X_k exhibit CRS. Therefore, the production function (3.1) can alternatively be written as

$$q_k = \left(\exp(z_k^q) \bar{A}_k \left(k_k^{\alpha_k} \ell_k^{Q, 1-\alpha_k} \right)^{\eta_k} \left(\prod_{s=1}^M x_{ks}^{\omega_{ks}^X} \right)^{1-\eta_k} \right)^{\chi_k}. \quad (\text{C.9})$$

The normalization constants, \bar{A}_k^Q , \bar{A}_k^V and \bar{A}_k^X , are defined as follows and imply that

$$\bar{A}_k = \bar{A}_k^Q \left(\bar{A}_k^V (\bar{A}_k^X)^{1-v_k} \right)^{1-\alpha_k \eta_k} \begin{cases} [\bar{A}_k^Q]^{-1} &= \chi_k (\alpha_k \eta_k)^{\alpha_k \eta_k} (1 - \alpha_k \eta_k)^{(1-\alpha_k \eta_k)} \\ [\bar{A}_k^V]^{-1} &= (v_k)^{v_k} (1 - v_k)^{(1-v_k)} \\ [\bar{A}_k^X]^{-1} &= \prod_{s=1}^M (\omega_{ks}^X)^{\omega_{ks}^X} \end{cases}$$

Consequently, the normalization constant of the sector-specific productivity level, $A_k = \exp(z_k^q) \bar{A}_k$, is given by

$$[\bar{A}_k]^{-1} = \chi_k \left[\eta_k \alpha_k^{\alpha_k} (1 - \alpha_k)^{(1-\alpha_k)} \right]^{\eta_k} \left[(1 - \eta_k) \prod_{s=1}^M (\omega_{ks}^X)^{\omega_{ks}^X} \right]^{1-\eta_k}$$

The productivity shocks z_k^q are normally distributed as $\mathcal{N}(0, \sigma_{q,k}^2)$ such that $A_k = \bar{A}_k$ in equilibrium.

Derivation of Optimization Problem. Total revenues of firm k from selling its output and providing trade credit to its customers are given by

$$R_k = \sum_{c=0}^M (1 - \theta_{ck}) p_k x_{ck} + (1 + r_k^T) \theta_{ck} p_k x_{ck} = \sum_{c=0}^M (1 + r_k^T \theta_{ck}) p_k x_{ck} = \phi_k^R p_k q_k \quad (\text{C.10})$$

where the last line substitutes the constraints of sector k for production (3.13) and trade credit extended (3.14), which are binding in equilibrium. Consequently, the revenue wedge, ϕ_k^R , and the average of trade credit share extended to firm k 's customers, θ_k^C , are

$$\phi_k^R = 1 + r_k^T \theta_k^C \quad (\text{C.11}) \quad , \quad \text{where} \quad \theta_k^C = \sum_{c=0}^M \theta_{ck} \frac{x_{ck}}{q_k} \quad (\text{C.12})$$

with $\theta_{0k} = 0$. The binding working capital constraint implies that total costs of production including interest payments are

$$(1 + r_k^B) BC_k + \sum_{s=1}^M (1 + r_s^T) \theta_{ks} p_s x_{ks} = \phi_k^L w \left(\ell_k^Q + \ell_k^T \right) + \sum_{s=1}^M \phi_{ks}^X p_s x_{ks} \quad (\text{C.13})$$

where the respective credit wedges are

$$\phi_k^L = 1 + r_k^B \quad (\text{C.14}) \quad \text{and} \quad \phi_{ks}^X = 1 + (1 - \theta_{ks}) r_k^B + r_s^T \theta_{ks} \quad (\text{C.15})$$

Note that the intermediate goods credit wedge equals a weighted average of the interest rates on bank and trade credit. Substituting for the binding working capital constraint implies that profits can be written as

$$\pi_k = \phi_k^R p_k q_k - \phi_k^L w \left(\ell_k^Q + \ell_k^T \right) - \sum_{s=1}^M \phi_{ks}^X p_s x_{ks} \quad (\text{C.16})$$

such that the intermediate goods firm's problem profit maximization problem implies that firm k chooses $\mathcal{V} = \{\ell_k^Q, \{x_{ks}\}_{s=1}^M, V_k, \{\theta_{ks}\}_{s=1}^M, \theta_k^C\}$ to maximize

$$V(z_k^q, z_k^b) = \max_{\mathcal{V}} \pi_k$$

subject to the production function (3.1), the credit management cost function (3.7), the interest rate on bank credit (3.8), feasibility constraints on trade credit shares $\theta_k^C, \theta_{ks} \in [0, 1]$ and non-negativity constraints for all variables.

Profit Maximization Problem. The firm's profit maximization problem is solved as a dual problem in two steps: (1) Given interest rates, \mathbf{r} , trade credit shares, Θ , the input composite, V_k , and average trade credit share demanded by customers, θ_k^C , firm k first chooses production inputs to minimize total costs of production. Having derived the cost-minimizing input expenditures, firm k then solves for the (2a) optimal level of output choosing, V_k , the optimal trade credit shares (2b) demanded from suppliers, $\{\theta_{ks}\}_{s=1}^M$ and (2c) extended to customers, θ_k^C . Each step will be discussed in detail in the following sections.

Proof of Lemma 3.1. (1) *Cost-Minimization.* For given credit links, the optimal input demand is derived in two steps: given total input expenditures, the firm minimizes expenditures on (a) composite inputs and (b) individual inputs.

(a) Let $p_k^V V_k$ be the cost-minimizing total expenditures on inputs solving

$$p_k^V V_k \equiv \min_{\ell_k^Q, X_k} \phi_k^L w \ell_k^Q + p_k^X X_k \quad \text{subject to} \quad V_k = \bar{A}_k^V \left(\ell_k^Q \right)^{v_k} \left(X_k \right)^{1-v_k}$$

where p_k^V is a composite of input costs and p_k^X is the price of the intermediate composite, X_k . The FOCs with respect to this problem imply that the minimum expenditures $p_k^V V_k$ to produce one unit of V_k are

$$p_k^V = \left(\phi_k^L w \right)^{v_k} \left(p_k^X \right)^{(1-v_k)}. \quad (\text{C.17})$$

The optimal demand for labor ℓ_k^Q and the composite intermediate input X_k is given by

$$\ell_k^Q = \frac{(1 - \alpha_k) \eta_k}{1 - \alpha_k \eta_k} \left(\frac{\phi_k^L w}{p_k^V} \right)^{-1} V_k \quad (\text{C.18}) \quad \text{and} \quad X_k = \frac{(1 - \eta_k)}{1 - \alpha_k \eta_k} \left(\frac{p_k^X}{p_k^V} \right)^{-1} V_k. \quad (\text{C.19})$$

(b) Similarly, let $p_k^X X_k$ be the cost-minimizing total expenditures on intermediate goods such that

$$p_k^X X_k \equiv \min_{\{x_{ks}\}_s} \sum_{s=1}^M \phi_{ks}^X p_s x_{ks} \quad \text{subject to} \quad X_k = \bar{A}_k^X \prod_{s=1}^M (x_{ks})^{\omega_{ks}^X}.$$

The FOCs imply that the aggregate price index of the composite intermediate good X_k is

$$p_k^X = \phi_k^X \prod_{s=1}^M (p_s)^{\omega_{ks}^X} \quad (\text{C.20}) \quad \text{where} \quad \phi_k^X = \prod_{s=1}^M (\phi_{ks}^X)^{\omega_{ks}^X}. \quad (\text{C.21})$$

The optimal demand for the intermediate input from supplier s , x_{ks} , is given by

$$x_{ks} = \omega_{ks}^X \left(\frac{\phi_{ks}^X p_s}{p_k^X} \right)^{-1} X_k = \omega_{ks}^X \frac{(1 - \eta_k)}{1 - \alpha_k \eta_k} \left(\frac{\phi_{ks}^X p_s}{p_k^V} \right)^{-1} V_k. \quad (\text{C.22})$$

Using Equation (C.18) and (C.22), total costs of *productive* inputs including interest payments are

$$C_k^Q = \phi_k^L w \ell_k^Q + \sum_{s=1}^M \phi_{ks}^X p_s x_{ks} = p_k^V V_k. \quad (\text{C.23})$$

Exploiting the result of Lemma 3.2 implies that optimal input demand for productive labor, ℓ_k^Q , and intermediate inputs, x_{ks} , can be re-written in terms of total revenues, $R_k = \phi_k^R p_k q_k$, to

$$\ell_k^Q = (1 - \alpha_k) \eta_k \chi_k \left(\frac{\phi_k^L w}{\phi_k^R p_k} \right)^{-1} q_k, \quad (\text{C.24}) \quad x_{ks} = \omega_{ks}^X (1 - \eta_k) \chi_k \left(\frac{\phi_{ks}^X p_s}{\phi_k^R p_k} \right)^{-1} q_k. \quad (\text{C.25})$$

This completes the derivation of the optimal input expenditures and therefore the proof of Lemma 3.1. \square

Proof of Corollary 3.1. For given credit costs, \mathbf{r} , and shares, Θ , the *marginal cost of production including interest-cost* equals the price of the labor and intermediate composite. Using the results of Lemma 3.1, marginal cost of production can be written as

$$p_k^V = \underbrace{\left(\phi_k^L \right)^{v_k} \left(\prod_{s=1}^M (\phi_{ks}^X)^{\omega_{ks}^X} \right)^{(1-v_k)}}_{= \phi_k^V} \underbrace{\left(w \right)^{v_k} \left(\prod_{s=1}^M (p_s)^{\omega_{ks}^X} \right)^{(1-v_k)}}_{= mc_k^V} \quad (\text{C.26})$$

where ϕ_k^V denotes the composite credit wedge which is a function of the credit links between sectors. The properties of ϕ_k^V with respect to $\mathbf{v} \in \{r_k^B, r_k^T, \theta_{ks}\}$ are given by

$$\frac{\partial \phi_k^V}{\partial \mathbf{v}} \frac{1}{\phi_k^V} = \frac{v_k}{\phi_k^L} \frac{\partial \phi_k^L}{\partial \mathbf{v}} + (1 - v_k) \sum_{s=1}^M \frac{\omega_{ks}^X}{\phi_{ks}^X} \frac{\partial \phi_{ks}^X}{\partial \mathbf{v}}$$

Straight forward calculations imply that

$$\frac{\partial \phi_k^V}{\partial \mathbf{v}} \frac{1}{\phi_k^V} = \begin{cases} 0 < \frac{v_k}{\phi_k^L} + (1 - v_k) \sum_{s=1}^M \omega_{ks}^X \frac{(1 - \theta_{ks})}{\phi_{ks}^X} & \text{for } \mathbf{v} = r_k^B \\ 0 < + (1 - v_k) \omega_{ks}^X \frac{\theta_{ks}}{\phi_{ks}^X} & \text{for } \mathbf{v} = r_s^T \\ 0 \leq - (1 - v_k) \omega_{ks}^X \frac{(r_k^B - r_s^T)}{\phi_{ks}^X} & \text{for } \mathbf{v} = \theta_{ks} \end{cases}$$

Corollary 3.1 therefore follows directly from Lemma 3.1. \square

Proof of Lemma 3.2. (2a) *Profit Maximization.* Using the results of Lemma 3.1 and Corollary 3.1, profits of firm k in Equation (C.16) can also be written as

$$\pi_k = \phi_k^R p_k q_k - p_k^V V_k - (1 + r_k^B) w \ell_k^T. \quad (\text{C.27})$$

The FOC with respect to V_k is given by

$$\frac{\partial \pi_k}{\partial V_k} : p_k^V V_k = (1 - \alpha_k \eta_k) \chi_k \phi_k^R p_k q_k. \quad (\text{C.28})$$

Equation (C.28) implies that total input expenditures (including interest rate costs) are a fraction of total revenues. The optimal goods price equals

$$p_k = \frac{MC_k^V}{MP_k^V} = \frac{\phi_k^V}{\phi_k^R} \frac{mc_k^V}{(1 - \alpha_k \eta_k) \chi_k q_k V_k^{-1}} \quad (\text{C.29})$$

and the effective mark-up over marginal costs of production, $\phi_k^V (\phi_k^R)^{-1}$, is a combination of credit and revenue wedges. This completes the derivation of the optimal price charged on sector k 's output and therefore the proof of Lemma 3.2. \square

Definition C.1 (Definition of MC-Wedge Elasticities). Define $\epsilon_{V,k}^B$ as the elasticity of the marginal cost wedge with respect to the interest rate on bank credit, and $\epsilon_{\epsilon,k}^B$ as the elasticity of $\epsilon_{V,k}^B$, with respect to the interest rate on bank credit as

$$\epsilon_{V,k}^B = \frac{\partial \phi_k^V}{\partial r_k^B} \frac{r_k^B}{\phi_k^V} \quad \text{and} \quad \epsilon_{\epsilon,k}^B = \frac{\partial \epsilon_{V,k}^B}{\partial r_k^B} \frac{r_k^B}{\epsilon_{V,k}^B} \quad (\text{C.30})$$

where

$$1 > E_{0,k} = \frac{\epsilon_{V,k}^B}{r_k^B} = \frac{v_k}{\phi_k^L} + (1 - v_k) \sum_{s=1}^M \omega_{ks}^X \frac{(1 - \theta_{ks})}{\phi_{ks}^X}$$

$$1 > E_{1,k} = -\frac{\partial E_{0,k}}{\partial r_k^B} = \frac{v_k}{(\phi_k^L)^2} + (1 - v_k) \sum_{s=1}^M \omega_{ks}^X \frac{(1 - \theta_{ks})^2}{(\phi_{ks}^X)^2}.$$

Assumption C.5 (Credit Cost Parameter μ). The interest rate on bank credit, r_k^B , is an increasing and convex function in θ_k^C , where

$$\mu > \underline{\mu} = \max \{ \mu_m^{LB} \}_{m=1}^M \quad (\text{C.31})$$

and

$$[\mu_m^{LB}]^{-1} = 1 - \frac{(E_{1,m} - E_{0,m}^2)}{E_{0,m}} r_m^Z = 1 - (1 - (\epsilon_{\epsilon,k}^V + \epsilon_{V,k}^B)) \frac{r_m^Z}{r_k^B} \quad (\text{C.32})$$

Derivation of Assumption C.5. Using

$$\frac{\partial^2 r_k^B}{\partial(\theta_k^C)^2} = \frac{(\mu - 1)}{(\theta_0^D + \theta_k^C)} \frac{\partial r_k^B}{\partial \theta_k^C} \quad \text{and} \quad \frac{\partial E_{0,k}}{\partial \theta_k^C} = -E_{1,k} \frac{\partial r_k^B}{\partial \theta_k^C}$$

the first and second order derivative of marginal costs, p_k^V , with respect to the average trade credit share extended to customers is given by

$$\begin{aligned} \frac{\partial p_k^V}{\partial \theta_k^C} &= \frac{\partial p_k^V}{\partial \phi_k^V} \frac{\partial \phi_k^V}{\partial r_k^B} \frac{\partial r_k^B}{\partial \theta_k^C} = E_{0,k} p_k^V \frac{\partial r_k^B}{\partial \theta_k^C} \\ \frac{\partial^2 p_k^V}{\partial(\theta_k^C)^2} &= \frac{\partial}{\partial \theta_k^C} \left(\frac{\partial p_k^V}{\partial \theta_k^C} \right) = \frac{\partial E_{0,k}}{\partial \theta_k^C} \frac{\partial r_k^B}{\partial \theta_k^C} p_k^V + E_{0,k} \frac{\partial^2 r_k^B}{\partial(\theta_k^C)^2} p_k^V + E_{0,k} \frac{\partial r_k^B}{\partial \theta_k^C} \frac{\partial p_k^V}{\partial \theta_k^C} \end{aligned}$$

The second order derivative can be alternatively written as

$$\frac{\partial^2 p_k^V}{\partial(\theta_k^C)^2} = \left[-(E_{1,k} - E_{0,k}^2) \frac{\partial r_k^B}{\partial \theta_k^C} + E_{0,k} \frac{(\mu - 1)}{(\theta_0^D + \theta_k^C)} \right] \frac{\partial r_k^B}{\partial \theta_k^C} p_k^V$$

Due to Jensen's Inequality for $f(\cdot)$ being a convex function

$$f \left(\sum_{s=1}^M w_s^v \phi_{ks}^v \right) \leq \sum_{s=1}^M w_s^v f(\phi_{ks}^v)$$

where $w_s^v \in \{v_k, \{(1 - v_k)\omega_{ks}^X\}_{s=1}^M\}$ and $\phi_{ks}^v \in \{(\phi_k^L)^{-1}, \{(1 - \theta_{ks})(\phi_{ks}^X)^{-1}\}_{s=1}^M\}$, it holds that $E_{1,k} > E_{0,k}^2$ which implies that $1 > \epsilon_{\epsilon,k}^V + \epsilon_{V,k}^B$. Then $0 < \frac{\partial^2 p_k^V}{\partial(\theta_k^C)^2} \forall k$ if $\mu > \underline{\mu}$ defined in Equation (C.31). \square

C.3.3 Optimal Credit Decisions

Proof of Lemma 3.3. (2b) *Profit Maximization.* Having derived the cost-minimizing input expenditures for given trade credit shares, Θ , the input composite, V_k , and average trade credit share demanded by customers, θ_k^C , firm k now chooses $\mathcal{V}_k = \{\{\theta_{ks}\}_{s=1}^M, V_k, \theta_k^C\}$ to maximise profits

$$\max_{\mathcal{V}_k} \phi_k^R p_k q_k - p_k^V V_k - (1 + r_k^B) w \ell_k^T$$

subject to the production function (3.1), credit management cost function (3.7), the interest rate on bank credit (3.8), and the feasibility constraint $\theta_k^C, \{\theta_{ks}\}_{s=1}^M \in [0, 1]$.

(a) The FOC with respect to $\{\theta_{ks}\}_{s=1}^M$ is given by

$$\frac{\partial \pi_k}{\partial \theta_{ks}} : - \left[\frac{\partial p_k^V}{\partial \theta_{ks}} V_k + (1 + r_k^B) \frac{\partial w \ell_k^T}{\partial \theta_{ks}} \right] - \lambda_1 = 0 \quad (\text{C.33})$$

where λ_1 is the Kuhn-Tucker Lagrange multiplier associated with the feasibility constraints. In other words, firm k chooses $\{\theta_{ks}\}_{s=1}^M$ in order to minimize total costs of production such that the combined change in the cost of production and managing credit lines associated with changing the share of trade credit obtained from k 's supplier is zero at the optimum. Applying the results of Section C.3.2 and assuming that the optimal $\theta_{ks} \in (0, 1) \forall k, s$, such that $\lambda_1 = 0$, the FOC yields the following optimal trade credit share

$$\theta_{ks} = \bar{\theta}_{ks}^\kappa + \frac{(\bar{\theta}_k^S)^2}{\kappa_{1,ks}^T} \frac{\Delta_{ks} p_s x_{ks}}{1 + r_k^B} \quad \text{where} \quad \bar{\theta}_{ks}^\kappa = \left(1 - \frac{\kappa_{0,ks}^T}{\kappa_{1,ks}^T} \bar{\theta}_k^S \right) \bar{\theta}_k^S \quad (\text{C.34})$$

and Equation (3.22) in the main text follows. Note that if firm k can adjust its credit portfolio frictionless such that $\kappa_{1,ks}^T = 0 \forall k, s$, then the optimal demand for trade credit is simply given by

$$\theta_{ks} = \begin{cases} 1 & \text{if } p_s x_{ks} \Delta_{ks} - (1 + r_k^B) \kappa_{0,ks}^T > 0 \quad \text{for } \Delta_{ks} > 0 \\ 0 & \text{if } p_s x_{ks} \Delta_{ks} - (1 + r_k^B) \kappa_{0,ks}^T < 0 \quad \text{for } \Delta_{ks} < 0 \end{cases} \quad (\text{C.35})$$

Thus, the introduction of non-linear management costs of credit lines and respective parameter choices ensures that the demand for trade credit will have an interior solution.

(b) The 2nd order derivative of π_k with respect to θ_{ks} is given by

$$\frac{\partial^2 \pi_k}{\partial (\theta_{ks})^2} = - \left[\frac{\partial^2 p_k^V}{\partial (\theta_{ks})^2} V_k + (1 + r_k^B) \frac{\partial^2 w \ell_k^T}{\partial (\theta_{ks})^2} \right] \quad (\text{C.36})$$

and - using Equation (C.34) - is negative at the optimum if

$$\frac{\Delta_{ks} (\theta_{ks} - \bar{\theta}_{ks}^\kappa)}{\phi_{ks}^X} < \frac{1}{1 - (1 - v_k) \omega_{ks}^X} \quad (\text{C.37})$$

holds. Note that $\Delta_{ks} (\theta_{ks} - \bar{\theta}_{ks}^\kappa)$ can be interpreted as the net-interest rate costs associated with choosing an optimal credit-portfolio share above or below the trade credit share determined solely by the parameters of the model, $\bar{\theta}_{ks}^\kappa$. The condition for a maximum as given by Equation (C.37) therefore implies an upper bound for the share of net-interest cost of optimal credit portfolio deviations, $\Delta_{ks} (\theta_{ks} - \bar{\theta}_{ks}^\kappa)$, in gross credit costs, ϕ_{ks}^X , related to financing k 's input expenditures on output from supplier s . While the LHS is $\in [0, 1)$, the RHS of condition is greater than one such that the optimal trade credit share θ_{ks} maximizes profits.

(c) In equilibrium, the following bounds need to hold for $\theta_{ks} \in (0, 1)$

$$g(\theta) = \frac{\theta_{ks} - \bar{\theta}_k^S}{\bar{\theta}_k^S} = \frac{\bar{\theta}_k^S}{\kappa_{1,ks}^T} \left(-\kappa_{0,ks}^T + \frac{\Delta_{ks} p_s x_{ks}}{(1 + r_k^B)} \right) \in \left(-1, \frac{1 - \bar{\theta}_k^S}{\bar{\theta}_k^S} \right)$$

and

$$g(\theta) \begin{cases} < 0 & \frac{p_s x_{ks}}{1 + r_k^B} < (>) \frac{\kappa_{0,ks}^T}{\Delta_{ks}} \text{ for } \Delta_{ks} > (<) 0 \\ > 0 & \frac{p_s x_{ks}}{1 + r_k^B} > (<) \frac{\kappa_{0,ks}^T}{\Delta_{ks}} \text{ for } \Delta_{ks} > (<) 0 \end{cases}$$

Taking intermediate expenditures and credit costs as given, the properties of the optimal trade credit share follow from straight forward calculations. This completes the derivation of the optimal trade credit share and thus portfolio choice between bank and trade credit to finance input expenditures from sector s and therefore concludes the proof of Lemma 3.3.

□

Total Credit Management Costs. The optimal trade credit share as given by Equation (3.22) implies that the profit-maximizing total non-productive labor expenditures are

$$w \ell_k^T = \kappa_k^B + \bar{\theta}_k^S \sum_{s=1}^M \kappa_{0,ks}^T \left(1 - \frac{\kappa_{0,ks}^T}{\kappa_{1,ks}^T} \frac{\bar{\theta}_k^S}{2} \right) + \frac{\bar{\theta}_k^S}{2} \sum_{s=1}^M \frac{\bar{\theta}_k^S}{\kappa_{1,ks}^T} \left(\frac{\Delta_{ks} p_s x_{ks}}{1 + r_k^B} \right)^2 \quad (\text{C.38})$$

Proof of Lemma 3.4. (2c) *Profit Maximization.* Having derived the cost-minimizing input expenditures for given trade credit shares, Θ , the input composite, V_k , and average trade credit share demanded by customers, θ_k^C , firm k now chooses $\mathcal{V}_k = \{\{\theta_{ks}\}_{s=1}^M, V_k, \theta_k^C\}$ to maximise profits while taking the demand for trade credit from their customers, $\{\theta_{ck}\}_{c=1}^M$, as given due to perfect competition.

$$\max_{\mathcal{V}_k} \phi_k^R p_k q_k - p_k^V V_k - (1 + r_k^B) w \ell_k^T$$

subject to the production function (3.1), credit management cost function (3.7), the interest rate on bank credit (3.8), and the feasibility constraint $\theta_k^C, \{\theta_{ks}\}_{s=1}^M \in [0, 1]$.

(a) The FOC with respect to θ_k^C is given by

$$\frac{\partial \pi_k}{\partial \theta_k^C} : \frac{\partial \phi_k^R}{\partial \theta_k^C} p_k q_k = \frac{\partial p_k^V}{\partial \theta_k^C} V_k + \frac{\partial r_k^B}{\partial \theta_k^C} w \ell_k^T \quad (\text{C.39})$$

where the feasibility constraint is non-binding. The interest rate on trade credit charged is the solution to Equation (C.39). In other words, firm k sets r_k^T in order to equalize the marginal revenue to marginal costs of extending trade credit to customers. The change in the cost of production associated with extending trade credit equals the total effect of trade credit demand on external borrowing costs internalized by firm k . Using the results of Lemma 3.1 and Corollary 3.1, the FOC implies that

$$r_k^T p_k q_k = \frac{\partial r_k^B}{\partial \theta_k^C} BC_k \quad \text{where} \quad BC_k = w(\ell_k^Q + \ell_k^T) + \sum_{s=1}^M (1 - \theta_{ks}) p_s x_{ks} \quad (\text{C.40})$$

Rearranging, the optimal interest rate on trade credit extended by sector k is given by

$$r_k^T = \mu \frac{r_k^Z}{\theta_k^Z} \frac{BC_k}{p_k q_k} \quad (\text{C.41a}) \quad \text{and} \quad r_k^T = \frac{r_k^Z BC_k}{\mu^{-1} \theta_k^Z R_k - r_k^Z \theta_k^C BC_k} \quad (\text{C.41b})$$

respectively, where $\frac{\partial r_k^B}{\partial \theta_k^C} = \mu r_k^Z (\theta_k^Z)^{-1}$ with $r_k^Z = r_k^B - x_0^B$ and $\theta_k^Z = \bar{\theta}_0^D + \theta_k^C$. Equation (C.41b) follows from rewriting Equation (C.41a) in terms of total revenues of firm k and rearranging. In other words, Equation (C.41a) implies that the optimal interest rate on trade credit charged equals the share of changes in total interest rate payments on bank loans due to changes in the average trade credit share extended to customers in total revenues net of revenues from financial intermediation.

(b) Assuming that Assumption C.5 holds such that $0 < \frac{\partial^2 p_k^V}{\partial(\theta_k^C)^2}$, the second order derivative with respect to θ_k^C is

$$\frac{\partial^2 \pi_k}{\partial(\theta_k^C)^2} = - \left[\frac{\partial^2 p_k^V}{\partial(\theta_k^C)^2} V_k + \frac{\partial^2 r_k^B}{\partial(\theta_k^C)^2} w \ell_k^T \right] < 0 \quad (\text{C.42})$$

Given demand for trade credit from firm k 's customers, r_s^T maximizes firm k 's profits.

(c) The properties of the equilibrium condition for interest rate on trade credit discussed in the main text follow from straight forward calculations. □

C.4 Propagation

The proofs of Corollary 3.2 to 3.4 in Section 3.2 follow from the previous sections and are described below. Let the demand structure be given by $G_L(\Omega)$. Consider a financial shock to the bank risk premium of the representative firm in sector k , $\epsilon_k^b > 0$, such that k 's risk premium (r_k^Z) and interest rate on bank credit (r_k^B) defined in Equation (3.8) increase.

Proof of Corollary 3.2. The proof follows directly from the properties of the marginal cost of production derived in Corollary 3.1, the optimal input demand derived in Lemma 3.1 and the profit maximizing price derived in Lemma 3.2. □

Proof of Corollary 3.3. The proof follows from the properties of the optimal interest rate charged on trade credit as shown in Lemma 3.4, the marginal cost of production derived in Corollary 3.1 and the optimal input demand derived in Lemma 3.1. □

Proof of Corollary 3.4. The optimal share of intermediate inputs obtained on trade credit from supplier s by sector k is derived in Lemma 3.4. Given intermediate expenditures and its supplier's interest rate charged on trade credit, the optimal trade credit share is increasing in the interest rate on bank loans as evident from Equation 3.22. The second part of the statement follows from Corollary 3.1 and

$$\begin{aligned} 0 < \frac{\partial p_k^V}{\partial r_k^B} &= + \left\{ \frac{v_k}{\phi_k^L} + (1 - v_k) \frac{(1 - \theta_{ks})}{\phi_{ks}^X} \right\} p_k^V \\ 0 > \frac{\partial^2 p_k^V}{\partial r_k^B \partial \theta_{ks}} &= - \left\{ 1 + v_k \left[1 - (1 - \theta_{ks}) \frac{\phi_k^L}{\phi_{ks}^X} \right] \frac{\Delta_{ks}}{\phi_k^L} \right\} (1 - v_k) \frac{p_k^V}{\phi_{ks}^X} \end{aligned}$$

This completes the proof of Corollary 3.4. □

C.5 Summary

Equilibrium Demand. Summarizing the results of Section C.1 to Section C.3.3, firm k 's cost-minimizing demand for inputs and the optimal share of intermediate input expenditures financed using trade credit are

- Household's Budget Constraint - (National Accounting) ($C, \#1$)

$$PC = wL + \sum_{m=1}^M \pi_m + \sum_{m=1}^M r_k^B BC_m \quad (\text{M.1})$$

- Optimal Labour Choice ($L, \#1$)

$$\frac{L^{\epsilon_L}}{C^{-\epsilon_C}} = \frac{w}{P} \quad (\text{M.2})$$

- Final Demand for Sectoral Output ($x_{0k}, \#M$)

$$x_{0k} = \omega_k^F \left(\frac{p_k}{P} \right)^{-1} F \quad (\text{M.3})$$

- Demand for Composite Factor ($p_k^V, \#M$)

$$V_k = (1 - \alpha_k \eta_k) \chi_k \left(\frac{p_k^V}{\phi_k^R p_k} \right)^{-1} q_k \quad (\text{M.4})$$

- Demand for Composite Intermediate Good ($p_k^X, \#M$)

$$X_k = (1 - \eta_k) \chi_k \left(\frac{p_k^X}{\phi_k^R p_k} \right)^{-1} q_k \quad (\text{M.5})$$

- Demand for Intermediate Good ($x_{ks}, \#M^2$)

$$x_{ks} = \omega_{ks}^X (1 - \eta_k) \chi_k \left(\frac{\phi_{ks}^X p_s}{\phi_k^R p_k} \right)^{-1} q_k \quad (\text{M.6})$$

- Demand for Productive Labour ($\ell_k^Q, \#M$)

$$\ell_k^Q = (1 - \alpha_k) \eta_k \chi_k \left(\frac{\phi_k^L w}{\phi_k^R p_k} \right)^{-1} q_k \quad (\text{M.7})$$

- Credit Management Costs ($\ell_k^T, \#M$)

$$w \ell_k^T = \kappa_k^B + \sum_{s=1}^M \kappa_{0,ks}^T \theta_{ks} + \sum_{s=1}^M \frac{\kappa_{1,ks}^T}{2} \left(\frac{\theta_{ks} - \bar{\theta}_k^S}{\bar{\theta}_k^S} \right)^2 \quad (\text{M.8})$$

- Demand for Trade Credit ($\theta_{ks}, \#M^2$)

$$\theta_{ks} = \left(1 - \bar{\theta}_k^S \frac{\kappa_{0,ks}^T}{\kappa_{1,ks}^T} \right) \bar{\theta}_k^S + \frac{(\bar{\theta}_k^S)^2}{\kappa_{1,ks}^T} \frac{\Delta_{ks} p_s x_{ks}}{(1 + r_k^B)} \quad (\text{M.9})$$

The respective credit wedges are defined below and sector k 's total bank loans are given by $BC_k = w\ell_k + \sum_{s=1}^M (1 - \theta_{ks})p_s x_{ks}$. Profits are $\pi_k = \phi_k^R p_k q_k - \phi_k^L w\ell_k - \sum_k^M \phi_{ks}^X p_s x_{ks}$.

Production and Interest Rates on Credit. The production and thus supply of intermediate, final and composite goods as well as the cost of credit implied by the optimal share of goods supplied on trade credit to customers are given by

- Intermediate Good Production Function ($q_k, \#M$)

$$q_k = \left(\exp(z_k^q) \bar{A}_k^Q \bar{k}_k^{\alpha_k \eta_k} V_k^{1-\alpha_k \eta_k} \right)^{\chi_k} \quad (\text{M.10})$$

- Composite Factor ($V_k, \#M$)

$$V_k = \bar{A}_k^V \left(\ell_k^Q \right)^{v_k} \left(X_k \right)^{1-v_k} \quad (\text{M.11})$$

- Composite Intermediate Good ($X_k, \#M$)

$$X_k = \bar{A}_k^X \prod_{s=1}^M x_{ks}^{\omega_{ks}^X} \quad (\text{M.12})$$

- Composite Final Good ($F_k, \#1$)

$$F = A_0 \prod_{m=1}^M x_{0m}^{\omega_{0m}^F} \quad (\text{M.13})$$

- Interest Rate on Bank Credit ($r_k^B, \#M$)

$$r_k^B = r_0^B + \exp(z_k^b) (\bar{\theta}_0^D + \theta_k^C)^\mu r_0^B \quad (\text{M.14})$$

- Interest Rate on Trade Credit ($r_k^T, \#M$)

$$r_k^T = \frac{\mu r_k^Z BC_k}{\bar{\theta}_k^Z p_k q_k} \quad (\text{M.15})$$

Factor and Credit Market Clearing Conditions. The respective market clearing conditions are as follows

- Intermediate Goods Market ($p_k, \#M$)

$$q_k = \sum_{c=0}^M x_{ck} \quad (\text{M.16})$$

- Final Goods Market - National Accounting ($P, \#1$)

$$F = C \quad (\text{M.17})$$

- Labor Market ($w, \#1$)

$$L = \sum_{k=1}^M \ell_k^Q + \ell_k^T \quad (\text{M.18})$$

- Trade Credit Market ($\theta_k^C, \#M$)

$$AR_k = \theta_k^C p_k q_k = \sum_{c=1}^M \theta_{ck} p_k x_{ck} = \sum_{c=1}^M AP_{ck} \quad (\text{M.19})$$

These equations represent a $(5 + 12M + 2M^2)$ system of equations (minus one after accounting for the numeraire) in the same number of unknowns:

(a) Aggregate Quantities (3): $\{C, F, L\}$

(b) Sectoral Quantities ($6M + M^2$): $\{\ell_k^Q, \ell_k^T, q_k, V_k, X_k, \{x_{ks}\}_{s=1}^M, x_{0k}\}_{k=1}^M$

(c) Prices ($2 + 3M$): $\{w, P, \{p_k^V, p_k^X, p_k\}_{k=1}^M\}$

(d) Credit Costs and Shares ($3M + M^2$): $\{r_k^B, r_k^T, \theta_k^C, \{\theta_{ks}\}_{s=1}^M\}_{k=1}^M$

When mapping the model to the data in Chapter 4, total nominal (\overline{M}_k) and real (x_{Mk}) imports as well as capital (\overline{k}_k) are treated as constants. Accounting for the numeraire (w) and substituting allows to reduce the number of equations to $(3 + 4M)$ with the following set of unknowns: $\{C, F, \{V_k, \theta_k^C\}_{k=1}^M, P, \{p_k, r_k^T\}_{k=1}^M\}$, which are used to simulate and solve for the equilibrium of the model directly in Chapter 4. In addition, the law of motion of the productivity and the bank risk premium $\{z_k^q, z_k^b\}_{k=1}^M$, respectively is $z_{kt}^v = \rho_v z_{kt-1}^v + \epsilon_{kt}^v$ for $v \in \{q, b\}$. Equilibrium credit wedges $\{\phi_k^R, \phi_k^V, \phi_k^X, \phi_k^L, \{\phi_{ks}^X\}_{s=1}^M\}_{k=1}^M$ and prices are summarized in the following:

Credit Wedges are given by the following $(4M + M^2)$ equations

- Marginal Cost Wedge ($\#M$)

$$\phi_k^V = (\phi_k^L)^{v_k} (\phi_k^X)^{(1-v_k)} \quad (\text{M.20})$$

- Labour Credit Cost Wedge ($\#M$)

$$\phi_k^L = 1 + r_k^B \quad (\text{M.21})$$

- Intermediate ($\#M^2$) and Composite Credit Cost Wedge ($\#M$)

$$\phi_k^X = \prod_{s=1}^M (\phi_{ks}^X)^{\omega_{ks}^X} \quad (\text{M.22})$$

$$\phi_{ks}^X = 1 + r_k^B - (r_k^B - r_s^T)\theta_{ks} \quad (\text{M.23})$$

- Revenue Wedge ($\#M$)

$$\phi_k^R = 1 + r_k^T \theta_k^C \quad (\text{M.24})$$

Note that if the financial distortions are exogenous like in an economy with bank-finance only, then $\phi_k^V = \phi_k$ for $V \in \{V, X, L\}$ and $\phi_k^R = 1$.

Equilibrium Price Indices. Using the results of Sections C.3.1 and C.3.2, prices fulfil the following equations in equilibrium

- Aggregate Price Index ($\#1$)

$$P = \prod_{k=1}^M (p_k)^{\omega_k^F} \quad (\text{M.25})$$

- Price Index of Composite Factor ($\#M$)

$$p_k^V = (\phi_k^L w)^{v_k} (p_k^X)^{(1-v_k)} \quad (\text{M.26})$$

- Price Index of Composite Intermediate Good ($\#M$)

$$p_k^X = \phi_k^X \prod_{s=1}^M p_s^{\omega_{ks}^X} \quad (\text{M.27})$$

- Price of Intermediate Good ($\#M$)

$$p_k = \frac{\phi_k^V (w)^{v_k} \left(\prod_{s=1}^M p_s^{\omega_{ks}^X} \right)^{(1-v_k)}}{\phi_k^R (1 - \alpha_k \eta_k) \chi_k q_k V_k^{-1}} \quad (\text{M.28})$$

D. Appendix to Chapter 3: Equilibrium

In this appendix, I derive the partial equilibrium of the model economy introduced in Chapter 3. For this purpose, Appendix D.1 first comments on the equilibrium level of capital and the national accounting in this economy. Appendix D.2 derives the partial equilibrium expressions of revenues, sales, output, aggregate GDP, labor, the aggregate efficiency and labor wedge following the same steps as in BL(2017) for given credit shares, Θ , and credit costs, \mathbf{r} . It should be noted that the partial equilibrium of this economy maps into similar expressions as derived in BL(2017). This should not come as a surprise since the model economy introduced in this thesis nests the economy in BL(2017) for $v = 0, \forall v \in \{\Theta, \ell^T\}$. However, endogenous trade credit linkages will distort the propagation of shocks as discussed in more detail in Section 3.2 and Appendix E. The results of this section will be used in the calibration of the model to the US economy, in order to be consistent with the national accounting in the input-output tables provided by the BEA and further discussed in Chapter 4.

D.1 National Accounting

Capital and Investment. The model presented in Chapter 3 is static, where capital is treated as a constant in the production function (3.1) and is equal to its steady state level. In order to derive the equilibrium level of capital used in the calibration of the model in Section 4.1, I now discuss the optimization problem of firm k for the case in which firms own and invest in their capital stock. As firm k now also purchases the final good for investment, i_k , profits of firm k are given by

$$\pi_k = \phi_k^R p_k q_k - \phi_k^L w \left(\ell_k^Q + \ell_k^T \right) - \sum_{s=1}^M \phi_{ks}^X p_s x_{ks} - P i_k. \quad (\text{D.1})$$

Define $\mathbf{z}_k = [z_k^q, z_k^b]$. The intermediate good firm k 's *profit maximization problem* can be formulated recursively as

$$V(\mathbf{z}_k, k) = \max_{\mathcal{V}, k'} \pi_k + \mathbb{E}_t m' V(\mathbf{z}'_k, k')$$

subject to the production function (3.1), the credit management cost function (3.7), the interest rate on bank credit (3.8), feasibility constraints on trade credit shares $\theta_k^C, \theta_{ks} \in [0, 1]$ and non-negativity constraints for all variables. The firm also faces the law of motion for capital, $k'_k = i_k + (1 - \delta)k_k$. In addition to the set of choice variables from the static optimization problem, \mathcal{V} , firm k now also chooses its capital stock for next period, k'_k . The capital euler equation is given by

$$P = \beta \mathbb{E} \left[\left(\frac{C}{C'} \right)^{\epsilon_C} \left(\alpha_k \eta_k \chi_k R'_k (k'_k)^{-1} + P'(1 - \delta) \right) \right] \quad (\text{D.2})$$

since the firm applies the stochastic discount factor of the household: $m = \beta^t \lambda = \beta^t (C_t)^{-\epsilon_C}$ and $m' = \beta^{t+1} (C_{t+1})^{-\epsilon_C}$. In equilibrium all variables are constant such that equilibrium nominal capital expenditures are given by

$$Pr_k^K = P \left[\frac{1}{\beta} - (1 - \delta) \right] k_k = \alpha_k \eta_k \chi_k R_k \quad (\text{D.3})$$

where $1 = \beta(1 + r_k^K - \delta)$. The law of motion of capital implies that equilibrium investment is given by $i_k = \delta k_k \forall k$. Given the static nature of the model and for the derivation of the equilibrium of the model, I assume that capital never depreciates, $\delta = 0$, such that investment for each firm, $i_k = 0 \forall k$, and therefore total investment equals $I = \sum_m^M i_m = 0$.

Revenue Decomposition. In equilibrium, revenues of the intermediate good producing firm are spent on the respective factors *including* credit costs and profits:

$$R_k = \phi_k^X p_k^X X_k + \phi_k^L w \ell_k^Q + Pr_k^K k_k + \Pi_k = \left\{ \left[(1 - \eta_k) + ((1 - \alpha_k) + \alpha_k) \eta_k \right] \chi_k + (1 - \chi_k) \right\} R_k.$$

Since firms are the owners of capital in this model, Π_k denotes the sum of total expenditures on *non-productive labour* including interest rate costs, $\phi_k^L w \ell_k^T$, and *dividends* net of firm k 's capital income, d_k . Define $s_k^\pi = (1 - \chi_k)$ and denote s_k^d as the share of Π_k spent on net dividend payments and $(1 - s_k^d)$ as the share spent on non-productive labour including interest rate costs, respectively. Total cost of production *including* interest rate costs are then

$$C_k = \phi_k^L w \ell_k + \sum_{s=1}^M \phi_{ks}^X p_s x_{ks} = p_k^V V_k + (1 - s_k^d) s_k^\pi R_k = s_k^C R_k \quad (\text{D.4})$$

where $s_k^C = (1 - \alpha_k \eta_k) \chi_k + (1 - s_k^d) s_k^\pi$ denotes the *total cost share in revenues*. Similarly, the share of revenues spent on *dividends* payments net of capital income, is simply given by $(1 - s_k^C)$.

Expenditure Decomposition. Total cost of production, C_k , can be decomposed into a share, $(1 - \theta_k^B)$, that is spent on actual input expenditures, and a share, θ_k^B , that is spent on bank interest payments. The equilibrium expenditures of sector k on bank interest payments, $r_k^B \sum_{s=1}^M (1 - \theta_{ks}) p_s x_{ks} + r_k^B w \ell_k$, equal

$$\theta_k^B C_k = \left[(1 - \eta_k) \chi_k \sum_{s=1}^M \omega_{ks}^X s_{ks}^X + s_k^L \left((1 - \alpha_k) \eta_k \chi_k + (1 - s_k^d) s_k^\pi \right) \right] R_k = s_k^B R_k$$

where $s_{ks}^X = r_k^B (1 - \theta_{ks}) / \phi_{ks}^X$, $s_k^L = r_k^B / \phi_k^L$ denote the shares of interest rate payments in the respective input expenditures. Furthermore, note that the share of interest rate expenditures in total production costs equals $\theta_k^B = s_k^B / s_k^C$. Then, total cost of production and credit management *excluding* bank interest rate costs are given by $(1 - \theta_k^B) C_k = (s_k^C - s_k^B) R_k$.

Total Value Added and Foreign Trade Adjustments. In anticipation of the adjustments of the IO-tables provided by the BEA required to ensure an appropriate mapping of the equilibrium of the model to the data, I also include equilibrium imports treated as constants since foreign trade relations are not modelled explicitly. A detailed description of the adjustments made to the IO-tables and their mapping to the model equations is provided in Appendix F.1. In particular, I assume that (1) total final demand faced by intermediate good producing firms also includes foreign demand (M_k^Q) and (2) total additional capital services (M_k^K) are imported and therefore not part of total domestic income.

In order to obtain analytical expressions of the partial equilibrium of this economy described in Appendix D.2, I account for the respective nominal imports as follows: Both sector specific imported demand ($M_k^Q = p_k x_{Mk} = \omega_k^F s_k^M wL$) as well as total imported demand ($M_0^Q = \sum_m M_m^Q = s_0^M wL$) are written as a share of total labor income. Sector specific imported capital services are expressed as a share of sectoral *domestic* revenues $M_k^K = s_k^K R_k$. Total nominal imports, \mathcal{M} , thus equal the sum of foreign demand and expenditures on foreign capital services

$$\mathcal{M} = \sum_{m=1}^M M_m^Q + M_m^K = s_0^M wL + \sum_{m=1}^M s_m^K R_m. \quad (\text{D.5})$$

Total nominal value added, $PY = PF - \mathcal{M}$, of this economy is then derived by consolidating the household and firm budget constraints and net-exports such that

$$PY = wL + \sum_{k=1}^M (1 - s_k^K) R_k - \phi_k^L w \ell_k - \sum_{s=1}^M \phi_{ks}^X p_s x_{ks} = wL + \sum_{k=1}^M (1 - s_k^C - s_k^K) R_k \quad (\text{D.6})$$

where the last equality uses the total cost share derived in the previous paragraphs. Similarly, total nominal final demand, $PF = PY + \mathcal{M}$, can be written as

$$PF = (1 + s_0^M) wL + \sum_{k=1}^M R_k - \sum_{s=1}^M (1 + r_s^T \theta_{ks}) p_s x_{ks} - w \ell_k = (1 + s_0^M) wL + \sum_{k=1}^M s_k^R R_k \quad (\text{D.7})$$

where $s_k^R = 1 - (s_k^C - s_k^B)$. Note that the market clearing condition of the final good sector is given by $PF = PC$. In other words, the final good is consumed by the domestic household only, who spends total domestic income (GDP) and imports on consumption expenditures. Note that the total income of households including imports and therefore equilibrium total consumption expenditures can be expressed as

$$PC = \mathcal{M} + \sum_{k=1}^M p_k q_k - \sum_{k=1}^M \sum_{s=1}^M p_s x_{ks} \quad (\text{D.8})$$

where the market clearing condition for aggregate trade credit has been applied.

D.2 Partial Equilibrium

Lemma D.1 (Revenues in PE). *Let the wage rate be the numeraire. Define s_0^M and s_k^R as shown in Appendix D.1. Then (a) the vector of revenues of intermediate good producers is given by*

$$\mathbf{R} = \mathbf{C}_R \Phi^R \Omega^F (\boldsymbol{\iota}(1 + s_0^M) - \mathbf{s}^M) L = \boldsymbol{\kappa}_\phi^R L \quad (\text{D.9})$$

where

$$\mathbf{C}_R = \left[\mathbf{I} - \Phi^R (\text{inv}(\Phi^X) \circ \Omega^X)' \text{diag}(\boldsymbol{\chi} \circ (\boldsymbol{\iota} - \boldsymbol{\eta})) - \Phi^R \Omega^F (\boldsymbol{\iota}(\mathbf{s}^R)') \right]^{-1} \quad (\text{D.10})$$

and the wedge-matrices Φ^R and Φ^X are defined as

$$\Phi^R = \mathbf{I} + \text{diag}(\mathbf{r}^T) \text{diag}(\boldsymbol{\iota}'(\mathbf{W} \circ \boldsymbol{\Theta})) \quad (\text{D.11})$$

$$\Phi^X = \mathbf{J} + \text{diag}(\mathbf{r}^B) (\mathbf{A}_\Theta - \boldsymbol{\Theta}) + \boldsymbol{\Theta} \text{diag}(\mathbf{r}^T) \quad (\text{D.12})$$

(b) and the revenues of the final good producer are

$$R_0 = \left(1 + s_0^M + (\mathbf{s}^R)' \boldsymbol{\kappa}_\phi^R \right) L \quad (\text{D.13})$$

Proof of Lemma D.1. (a) The revenues of the *Intermediate Goods Firm* k are

$$R_k = \phi_k^R p_k q_k = \phi_k^R p_k \left(\sum_{c=0}^M x_{ck} - x_{Mk} \right). \quad (\text{D.14})$$

The left-hand side of Equation (D.14) represents the revenues generated by selling the domestically produced output, q_k , and the right hand side denotes revenues generated by total demand net of quantity-imports. Note that total domestic demand, $\sum_{c=0}^M x_{ck}$, can exceed domestic production, q_k , in the calibration of the model using actual data (e.g. Oil-Sector). Therefore, the revenues generated from selling imported output are deducted from sales based on total domestic demand. Consequently, R_k represents the revenues generated by *domestically produced output* only. Using the optimal demand for sector k 's output from both intermediate and final good producing firms as given by Equation (C.22) and (C.5), respectively, the revenues of the intermediate good firm k can be written as

$$\begin{aligned} R_k &= \phi_k^R p_k \left[\sum_{c=1}^M \frac{\omega_{ck}^X (1 - \eta_c) \chi_c}{\phi_{ck}^X p_k} R_c + \frac{\omega_k^F}{p_k} (R_0 - s_k^M w L) \right] \\ &= \sum_{c=1}^M \left(\frac{\phi_k^R}{\phi_{ck}^X} \right) \omega_{ck}^X (1 - \eta_c) \chi_c R_c + \phi_k^R \omega_k^F \left[(1 + s_0^M - s_k^M) w L + \sum_{m=1}^M s_m^R R_m \right] \end{aligned}$$

where the last line uses the definitions of Appendix D.1. Define the vector of revenues of

the intermediate goods firm as $\mathbf{R} = [R_1 \cdots R_M]'$. Then stacking yields the following system of equations

$$\mathbf{R} = \Phi^R \left[(\text{inv}(\Phi^X) \circ \Omega^X)' \text{diag}(\chi \circ (\iota - \eta)) + \Omega^F (\iota(s^R)') \right] \mathbf{R} + \Phi^R \Omega^F (\iota(1 + s_0^M) - s^M) (wL)$$

where the entries of matrices Φ^R and Φ^X are defined in Lemma D.1. Rearranging yields Equation (D.9) where the coefficient matrix \mathcal{C}_R is defined in Equation (D.10) with typical entry

$$[(\mathcal{C}_R)^{-1}]_{ck} = 1|_{c=k} - (1 + r_k^T \theta_k^C) \left[\frac{\omega_{ck}^X (1 - \eta_c) \chi_c}{1 + r_c^B (1 - \theta_{ck}) + r_k^T \theta_{ck}} + \omega_k^F s_k^R \right]$$

(b) The revenues of the *Final Good Firm* equal final consumption sales, $R_0 = PF = PC$. Using the results of Appendix D.1 and Equation (D.9), Equation (D.13) depicting the revenues of the final good producer follows from direct calculations. \square

Lemma D.2 (Prices in PE). *(a) Let the wage rate w be the numeraire. Then the vector of partial equilibrium sectoral prices is*

$$\begin{aligned} \log(\mathbf{p}) = & \mathcal{C}_P \left[-\chi \circ \log(\mathbf{z}^q) + \log(\phi^P) \right] \\ & + \mathcal{C}_P \left[(\iota - \chi) \circ \log(\kappa_\phi^R) + (\iota - \chi) \log(L) + (\chi \circ \alpha \circ \eta) \circ \log(\mathbf{r}^K) \right] \end{aligned} \quad (\text{D.15})$$

where the coefficient matrix is defined as

$$\mathcal{C}_P = \left[\mathbf{I} - \text{diag}(\chi \circ (\iota - \eta)) \Omega^X - \text{diag}(\chi \circ \alpha \circ \eta) (\iota \omega_F') \right]^{-1} \quad (\text{D.16})$$

and the vector of price wedges is given by

$$\log(\phi^P) = \chi \circ (\iota - \alpha \circ \eta) \circ \log(\phi^V) - \log(\phi^R) \quad (\text{D.17})$$

(b) The aggregate price level is given by

$$\log(P) = \omega_F' \log(\mathbf{p}) \quad (\text{D.18})$$

Proof of Lemma D.2. (a) Substituting for output of sector k in $R_k = \phi_k^R p_k q_k$ using sector k 's production function as given in Equation (C.9) as well as the profit maximizing intermediate input composite (C.28) and capital (D.3), yields

$$R_k = \phi_k^R p_k \left[\exp(z_k^q) R_k (Pr_k^K)^{-\alpha_k \eta_k} (p_k^V)^{-(1-\alpha_k \eta_k)} \right]^{\chi_k}$$

Applying the results of Corollary 3.1, taking logs and rewriting yields

$$\begin{aligned} \log(p_k) - (1 - \eta_k) \chi_k \sum_{m=1}^M \omega_{km}^X \log(p_m) - \alpha_k \eta_k \chi_k \sum_{m=1}^M \omega_m^F \log(p_m) &= \dots \\ \log(\phi_k^P) + (1 - \chi_k) \log(R_k) - \chi_k [\log(z_k^q) - \alpha_k \eta_k \log(r_k^K) - (1 - \alpha_k) \eta_k \log(w)] & \quad (\text{D.19}) \end{aligned}$$

where $\log(\phi_k^P) = (1 - \alpha_k \eta_k) \chi_k \log(\phi_k^V) - \log(\phi_k^R)$. Stacking Equation (D.19) for all sectors and using that $\mathbf{R} = \boldsymbol{\kappa}_\phi^R(wL)$ implies that the vector of sectoral prices is given by Equation (D.15), where the wage rate was chosen as the numeraire.

(b) From Section C.3.1 the aggregate price level is given by

$$P = \prod_{m=1}^M p_m^{\omega_m^F}, \text{ and in logs } \log(P) = \sum_{m=1}^M \omega_m^F \log(p_m) \quad (\text{D.20})$$

which can be rewritten in matrix form as shown in Equation (D.28). \square

Lemma D.3 (Sectoral Output in PE). *Let the wage rate w be the numeraire. The vector of sectoral output is given by*

$$\begin{aligned} \log(\mathbf{q}) &= + [\mathbf{I} - \mathbf{C}_P \text{diag}(\boldsymbol{\iota} - \boldsymbol{\chi})] [\log(\boldsymbol{\kappa}_\phi^R) + \boldsymbol{\iota} \log(L)] \\ &\quad - \boldsymbol{\phi}^Q + \mathbf{C}_P \text{diag}(\boldsymbol{\chi}) [\log(\mathbf{z}^q) - (\boldsymbol{\alpha} \circ \boldsymbol{\eta}) \circ \log(\mathbf{r}^K)] \end{aligned} \quad (\text{D.21})$$

where the output wedge is defined as

$$\boldsymbol{\phi}^Q = \mathbf{C}_P \log(\boldsymbol{\phi}^P) + \log(\boldsymbol{\phi}^R). \quad (\text{D.22})$$

Proof of Lemma D.3. The vector of sectoral output is derived as follows

$$\begin{aligned} \log(\mathbf{q}) &= \log(\mathbf{R}) - \log(\mathbf{p}) - \log(\boldsymbol{\phi}^R) \\ &= + [\mathbf{I} - \mathbf{C}_P \text{diag}(\boldsymbol{\iota} - \boldsymbol{\chi})] [\log(\boldsymbol{\kappa}_\phi^R) + \boldsymbol{\iota} \log(wL)] \\ &\quad - \boldsymbol{\phi}^Q + \mathbf{C}_P \text{diag}(\boldsymbol{\chi}) [\log(\mathbf{z}^q) - (\boldsymbol{\alpha} \circ \boldsymbol{\eta}) \circ \log(\mathbf{r}^K) - (\boldsymbol{\iota} - \boldsymbol{\alpha}) \circ \boldsymbol{\eta} \log(w)] \end{aligned}$$

where the last line uses the results of Lemma (D.1) and (D.2) and the vector of sectoral output wedges is defined in Equation (D.22). Taking the nominal wage rate w as the numeraire yields Equation (D.21). Note that the production parameters are such that $[\mathbf{I} - \mathbf{C}_P \text{diag}(\boldsymbol{\iota} - \boldsymbol{\chi})] \mathbf{x} > \mathbf{0}$ for any vector \mathbf{x} which implies that an increase in revenues positively influences output. \square

Definition D.1 (Efficiency Wedge). Define $\mathbf{C}_Y = \boldsymbol{\omega}'_F \mathbf{C}_P$ and let the aggregate labor share and productivity be defined as

$$\lambda = \mathbf{C}_Y (\boldsymbol{\iota} - \boldsymbol{\chi}) \quad (\text{D.23}) \quad \text{and} \quad \log(Z_z) = \mathbf{C}_Y \text{diag}(\boldsymbol{\chi}) \log(\mathbf{z}^q) \quad (\text{D.24})$$

The efficiency wedge is given by

$$\log(\Phi_\phi^Z) = \log(\Phi_\Phi^Z) + \log(\Phi_K^Z) + \log(\Phi_M^Z) \quad (\text{D.25})$$

where the components attributed to (D.26a) to (D.26c) are defined as follows

(a) credit costs

$$\log(\Phi_\Phi^Z) = \left[-\mathbf{C}_Y \log(\phi^P) - \mathbf{C}_Y \text{diag}(\boldsymbol{\iota} - \boldsymbol{\chi}) \log(\boldsymbol{\kappa}_\phi^R) + \log(\boldsymbol{\kappa}_\phi^Y) \right] \Big|_{\mathcal{M}=0} \quad (\text{D.26a})$$

(b) internal rental rate of equilibrium capital

$$\log(\Phi_K^Z) = -\mathbf{C}_Y \text{diag}(\boldsymbol{\chi} \circ \boldsymbol{\alpha} \circ \boldsymbol{\eta}) \log(\mathbf{r}^K) \quad (\text{D.26b})$$

(c) foreign trade and capital adjustments

$$\log(\Phi_M^Z) = \log(\Phi_\phi^Z) - \log(\Phi_\Phi^Z) - \log(\Phi_K^Z) \quad (\text{D.26c})$$

The aggregate share of total value added in aggregate labor supply is given by

$$\boldsymbol{\kappa}_\phi^Y = \boldsymbol{\iota}' \boldsymbol{\kappa}_\phi^Y = 1 + \sum_{m=1}^M [1 - s_m^C - s_m^K] [\boldsymbol{\kappa}_\phi^R]_m \quad (\text{D.27})$$

where the respective cost-shares are defined in Section D.1.

Derivation of Definition D.1. Define $\mathbf{C}_Y = \boldsymbol{\omega}'_F \mathbf{C}_P$. Using Equation (D.15), the log of the aggregate price index, $P = \boldsymbol{\omega}'_F \log(\mathbf{p})$, can be written as

$$\begin{aligned} P = & + \mathbf{C}_Y \log(\phi^P) + \mathbf{C}_Y \text{diag}(\boldsymbol{\iota} - \boldsymbol{\chi}) \log(\boldsymbol{\kappa}_\phi^R) + \mathbf{C}_Y \text{diag}(\boldsymbol{\chi} \circ \boldsymbol{\alpha} \circ \boldsymbol{\eta}) \log(\mathbf{r}^K) \\ & - \mathbf{C}_Y \text{diag}(\boldsymbol{\chi}) \log(\mathbf{z}^q) + \mathbf{C}_Y (\boldsymbol{\iota} - \boldsymbol{\chi}) \log(L) \end{aligned}$$

Collecting terms yields

$$P = - \left[\log(\Phi_\phi^Z) - \log(\kappa_\phi^Y) \right] - \log(Z_z) + \lambda \log(L) \quad (\text{D.28})$$

where the corresponding elements are defined in Equation (D.23) to (D.26c). The sectoral share of total value added in aggregate labor supply is given by

$$\kappa_\phi^Y = \mathbf{s}^Y \circ \kappa_\phi^R \quad (\text{D.29})$$

where the sectoral share of value added in revenues, \mathbf{s}^Y , is defined in Equation (D.31). Note that due to the market-clearing

$$1 = \sum_{m=1}^M (1 - s_m^L) [(1 - \alpha_m) \eta_m \chi_m + (1 - s_m^d) s_m^\pi] [\kappa_\phi^R]_m$$

holds in equilibrium and Equation (D.29) follows. \square

Lemma D.4 (Value Added in PE). *Let the wage rate w be the numeraire and let the corresponding expenditures shares, $s_k^L, s_{ks}^X, s_k^d, s_k^\pi$ and s_k^K be defined in Appendix D.1.*

(a) *Real sectoral value added is given by*

$$\log(\mathbf{y}) = \left[\iota \log(\Phi_\phi^Z) - (\iota \log(\kappa_\phi^Y) - \log(\kappa_\phi^R)) \right] + \iota \left[\log(Z_z) + (1 - \lambda) \log(L) \right] \quad (\text{D.30})$$

where the share of value added of sector k in sector k 's revenues is

$$[\mathbf{s}^Y]_k = \left[(1 - s_k^L) ((1 - \alpha_k) \eta_k \chi_k + (1 - s_k^d) s_k^\pi) \right] + \left[1 - s_k^C - s_k^K \right] \quad (\text{D.31})$$

(b) *Real aggregate GDP equals the sum of sectoral value added*

$$Y = Z_z \Phi_\phi^Z L^{(1-\lambda)} \quad (\text{D.32})$$

where Z_z denotes aggregate productivity and Φ_ϕ^Z equals the aggregate efficiency wedge defined in Definition D.1.

Proof of Lemma D.4. (a) Value added of sector k equals total labour expenditures and profits net of capital imports.

$$Py_k = w\ell_k + \pi_k - s_k^K R_k = s_k^Y R_k = [\kappa_\phi^Y]_k L$$

Using the accounting results of Appendix D.1 as well as Lemma 3.1, the share of sectoral value added in revenues, s_k^Y , is defined in Equation (D.31). Substituting for revenues using Equation (D.9) allows to rewrite sectoral value added as a share of aggregate labor supply, $[\kappa_\phi^Y]_k$, as defined in Equation (D.29). Stacking, taking logs and applying Equation (D.28), yields the vector of log real value added for all firms as shown in Equation (D.30).

(b) Real GDP equals the sum of sectoral value added is given by.

$$PY = P \sum_{k=1}^M y_k = wL + \sum_{k=1}^M (1 - s_k^C - s_k^K) R_k = \sum_{k=1}^M s_k^Y R_k = \iota' \kappa_\phi^Y L$$

Taking logs, defining the wage rate as the numeraire and applying Equation (D.28) yields

$$\log(Y) = -\log(P) + \log(\kappa_\phi^Y) + \log(L) = \log(Z_z) + \log(\Phi_\phi^Z) + (1 - \lambda) \log(L)$$

such that the aggregate production function is given in Equation (D.32). \square

Lemma D.5 (Aggregate Labor and Output in GE). *Let the wage rate w be the numeraire.*

(a) *Assuming that aggregate consumption is a share γ of GDP, Y , aggregate labor supply is given by*

$$\log(L) = \kappa_L^Z [\log(Z_z) + \log(\Phi_\phi^Z)] - \kappa_L^L [\log(\kappa_\phi^Y) + \epsilon_C \log(\gamma)] \quad (\text{D.33})$$

where

$$\kappa_L^Z = \frac{1 - \epsilon_C}{1 + \epsilon_L - (1 - \epsilon_C)(1 - \lambda)}, \quad \kappa_L^L = \frac{1}{1 + \epsilon_L - (1 - \epsilon_C)(1 - \lambda)} \quad (\text{D.34})$$

(b) *Aggregate GDP is then defined as*

$$\log(Y) = \kappa_Y^Z [\log(Z_z) + \log(\Phi_\phi^Z)] - \kappa_Y^L [\log(\kappa_\phi^Y) + \epsilon_C \log(\gamma)] \quad (\text{D.35})$$

where

$$\kappa_Y^Z = \frac{1 + \epsilon_L}{1 - \epsilon_C} \kappa_L^Z, \quad \kappa_Y^L = (1 - \lambda) \kappa_L^L \quad (\text{D.36})$$

Proof of Lemma D.5. From the household's problem presented in Section C.2, the log of labor supply is

$$\epsilon_L \log(L) = \log(w) - \log(P) - \epsilon_C \log(C)$$

Taking the nominal wage rate as the numeraire, assuming that aggregate consumption is a share γ of GDP, Y , and using Equation (D.28) and (D.32), aggregate labor supply is

$$[\epsilon_L + \epsilon_C(1 - \lambda)] \log(L) = -\lambda \log(L) - \log(\kappa_\phi^Y) + (1 - \epsilon_C) [\log(Z_z) + \log(\Phi_\phi^Z)] - \epsilon_C \log(\gamma)$$

Rearranging and collecting terms yields Equation (D.33).

(b) Substituting for equilibrium aggregate labor supply, L , in Equation (D.32) yields aggregate GDP as shown in Equation (D.35). \square

Definition D.2 (Efficiency Wedge). *Following BL(2017) and applying the concepts introduced in Chari et al. (2007), the aggregate labor wedge, Φ_ϕ^L , is defined as*

$$-\frac{U_L}{U_C} = \frac{w}{P} = \Phi_\phi^L(1 - \lambda)YL^{-1}.$$

It denotes the wedge between the household's marginal rate of substitution between consumption and labor and the aggregate marginal product of labor. Using the results of Lemma D.5 the aggregate labor wedges equals

$$\log(\Phi_\phi^L) = -\log(1 - \lambda) - \log(\kappa_\phi^Y).$$

E. Appendix to Chapter 3: Log-Linearization

In this appendix I log-linearize the model around its steady state derived in Appendix D, using $x = \bar{x} \exp(\hat{x}) \approx \bar{x}(1 + \hat{x})$ and $\hat{x} = \text{dlog}(x) = \log x / \bar{x}$. I first derive the log-linearized equilibrium responses of revenues, prices and sectoral output in terms of (1) productivity shocks, (2) general equilibrium adjustments in the aggregate labor supply and (3) distortions introduced as credit wedges in Appendix E.1. The credit wedges summarize the composite effect of changes in credit costs and the composition of credit portfolios on sectoral sales, prices and output. Appendix E.2 derives the decomposition of credit wedges into effects attributed to changes in interest rates on bank and trade credit and changes in trade credit shares. The log-linearized response of credit costs and shares is discussed in Appendix E.3. Appendix E.4 and E.5 derive the first order approximation of the partial equilibrium structural credit and output responses discussed in the main text.

To introduce additional notation, the effect of the log-changes of the variables of interest are determined by the entries of the corresponding elasticity matrices \mathbf{E} , which are non-linear functions of the steady state of the economy. Furthermore, define the following variables

- Net Accounts Payable of m paid to s equal to Net Accounts Receivable of s from m

$$\overline{AP}_{ms} = \bar{\theta}_{ms} \bar{p}_s \bar{x}_{ms} = \overline{AR}_{ms}$$

- Net Cash on Delivery of m paid to s equal to Net Cash on Delivery of m paid to s

$$\overline{AP}_{ms}^- = (1 - \bar{\theta}_{ms}) \bar{p}_s \bar{x}_{ms} = \overline{AR}_{ms}^-$$

In the subsequent derivations, the following simplifying assumptions are made: (1) I abstract from productivity shocks and consider the partial equilibrium case only, assuming that both productivity and aggregate labor remain at their steady state levels. (2) I treat

the share of quantities sold to intermediate and final good producers in total production as constant. (3) While Appendix D discussed the introduction of imports as constants for the purpose of ensuring a proper mapping of the model to the data, this appendix only considers the case of a closed economy. The wage rate is taken as the numeraire and capital is constant such that $\hat{k}_k = 0$.

E.1 Log-Linearized Equilibrium

Definition E.1 (Log-Linearized Equilibrium). *The log-linearized equilibrium given by:*

(a) *The response of intermediate and final sales is given by*

$$\hat{R}_k = \sum_{m=1}^M [\mathbf{W}_R^R]_{km} [\mathbf{E}_R^L]_{mm} \hat{L} - [\hat{\phi}_\kappa^R]_m, \text{ where } [\hat{\phi}_\kappa^R]_m = \sum_{m=1}^M [\mathbf{W}_R^R]_{km} [\hat{\phi}_\kappa^S]_m \quad (\text{E.1})$$

$$\hat{R}_0 = \left\{ E_F^L + \sum_{m=1}^M \sum_{n=1}^M [\mathbf{W}_F^R]_{nn} [\mathbf{W}_R^R]_{nm} [\mathbf{E}_R^L]_{mm} \right\} \hat{L} - \hat{\phi}_\kappa^F \quad (\text{E.2})$$

and

$$[\mathbf{W}_R^R]^{-1} = \mathbf{I} - (\mathbf{W}_R^X)' - \mathbf{W}_R^F \mathbf{J} \mathbf{W}_F^R. \quad (\text{E.3})$$

The intermediate, $\hat{\phi}_{\kappa,k}^S$, and final, $\hat{\phi}_\kappa^F$, sales wedges are defined in E.2.

(b) *The log-linearized responses of the price of sector k 's output and the aggregate price level are*

$$\hat{p}_k = \hat{\phi}_{\kappa,k}^P + [\mathbf{E}_P^L]_{kk} \hat{L} - \sum_{m=1}^M [\mathbf{E}_P^{Z_q}]_{km} \hat{z}_m^q \text{ and } \hat{P} = \sum_{m=1}^M \omega_m^F \hat{p}_m. \quad (\text{E.4})$$

The intermediate price wedge, $\hat{\phi}_{\kappa,k}^P$, is defined in E.2.

(c) *Using Equation (E.1) and (E.4) the response of sectoral output is*

$$\hat{q}_k = \sum_{m=1}^M [\mathbf{E}_Q^{Z_q}]_{km} \hat{z}_m^q - \hat{\phi}_k^Q + [\mathbf{E}_Q^L]_{kk} \hat{L} \quad (\text{E.5})$$

The intermediate output wedge, $\hat{\phi}_k^Q$, is defined in E.2.

The entries of the elasticity matrices are given by

$$\begin{aligned} \bar{R}_0 E_F^L &= \bar{L} \text{ and } [\mathbf{E}_R^L]_{kk} = [\mathbf{W}_R^F]_{kk} E_F^L & \bar{R}_k [\mathbf{W}_R^X]_{ck} &= \bar{\phi}_k^R \bar{p}_k \bar{x}_{ck} \\ \mathbf{E}_P^L &= \mathbf{W}_P^R \mathbf{W}_R^F E_F^L \boldsymbol{\iota} & \bar{R}_k [\mathbf{W}_R^F]_{kk} &= \bar{\phi}_k^R \bar{p}_k \bar{x}_{0k} \\ \mathbf{E}_Q^L &= \mathbf{W}_R^R \mathbf{E}_R^L \boldsymbol{\iota} - \mathbf{E}_P^L & \mathbf{E}_P^{Z_q} &= \mathbf{W}_P^P \text{diag}(\boldsymbol{\chi}) \\ \bar{R}_0 [\mathbf{W}_F^R]_m &= \bar{R}_m - \sum_{s=1}^M (1 + \bar{r}_s^T \bar{\theta}_{ms}) \bar{p}_s \bar{x}_{ms} - \bar{w} \bar{\ell}_m^Q & \mathbf{E}_Q^{Z_q} &= \mathbf{E}_P^{Z_q} \end{aligned} \quad (\text{E.6})$$

Definition E.2 (Equilibrium Distortions). *The effect of changes in credit costs and shares on sales, prices and output are summarized in the following wedges:*

- (a) *The intermediate sales credit wedge, $\phi_{\kappa,k}^S$, defined in Equation (E.7), summarizes the effect of changes in credit costs and the composition of credit on sector k 's sales.*

$$\widehat{\phi}_{\kappa,k}^S = \sum_{c=1}^M [\mathbf{W}_R^X]_{ck} \widehat{\phi}_{ck}^X - \widehat{\phi}_k^R + [\mathbf{W}_R^F]_{kk} \widehat{\phi}_F^S. \quad (\text{E.7})$$

Similarly, the final sales wedge is

$$\widehat{\phi}_{\kappa}^F = \sum_{m=1}^M \sum_{n=1}^M [\mathbf{W}_F^R]_{nn} [\mathbf{W}_R^R]_{nm} [\widehat{\phi}_{\kappa}]_m + \widehat{\phi}_F^S \quad (\text{E.8})$$

where

$$\widehat{\phi}_F^S = \sum_{m=1}^M \sum_{s=1}^M [\mathbf{W}_F^T]_{ms} \widehat{r}_s^T + [\mathbf{W}_F^{\theta}]_{ms} \widehat{\theta}_{ms} - [\mathbf{W}_F^{\Phi}]_{ms} \widehat{\phi}_{ms}^X - [\mathbf{W}_F^{\phi}]_m \widehat{\phi}_m^L. \quad (\text{E.9})$$

- (b) *The price credit wedge, $\phi_{\kappa,k}^P$, defined in Equation (E.10), is a composite of the effect of credit costs and trade credit shares on marginal cost of production and sales due to DRS. An increase in the price wedge increases prices.*

$$\widehat{\phi}_{\kappa,k}^P = \sum_{m=1}^M [\mathbf{W}_P^P]_{km} \widehat{\phi}_{P,m}^P - [\mathbf{W}_P^R]_{km} \widehat{\phi}_{\kappa,m}^S \quad (\text{E.10})$$

where

$$\widehat{\phi}_{P,k}^P = (1 - \alpha_k) \eta_k \chi_k \widehat{\phi}_k^L + (1 - \eta_k) \chi_k \sum_{s=1}^M \omega_{ks}^X \widehat{\phi}_{ks}^X - \widehat{\phi}_k^R. \quad (\text{E.11})$$

and defining $\bar{\chi}_k = (1 - \alpha_k \eta_k) \chi_k$,

$$[\mathbf{W}_P^P]^{-1} = \mathbf{I} - \text{diag}(\chi \circ (\boldsymbol{\iota} - \boldsymbol{\eta})) \boldsymbol{\Omega}^X \quad \text{and} \quad \mathbf{W}_P^R = \mathbf{W}_P^P \text{diag}(\boldsymbol{\iota} - \bar{\boldsymbol{\chi}}) \mathbf{W}_R^R. \quad (\text{E.12})$$

- (c) *The output wedge, ϕ_k^Q , defined in Equation (E.13), summarizes the total effect of credit costs and linkages on sectoral output and is a combination of the sales (E.7) and prices wedges (E.10). An increase in the output wedge decreases output.*

$$\widehat{\phi}_k^Q = \sum_{m=1}^M [\mathbf{W}_P^P]_{km} [\widehat{\phi}_P^P]_m + \widehat{\phi}_k^R + \sum_{m=1}^M ([\mathbf{W}_R^R]_{km} - [\mathbf{W}_P^R]_{km}) [\widehat{\phi}_{\kappa}^S]_m. \quad (\text{E.13})$$

In addition, let

$$\Delta_{PR} = \mathbf{W}_P^P - \mathbf{W}_P^R \quad \text{and} \quad \Delta_{RP} = \mathbf{W}_R^R - \mathbf{W}_P^R. \quad (\text{E.14})$$

and the entries of the elasticity matrices are given by

$$\begin{aligned}
\bar{R}_0[\mathbf{W}_F^\Phi]_{ms} &= (1 + \bar{r}_s^T \bar{\theta}_{ms}) \bar{p}_s \bar{x}_{ms} & \bar{R}_0[\mathbf{W}_F^\phi]_m &= \bar{w} \ell_m^Q \\
\bar{R}_0[\mathbf{W}_F^\theta]_{ms} &= (1 + \bar{r}_s^T) \bar{r}_s^B \bar{A} \bar{P}_{ms} (\bar{\phi}_m^L)^{-1} & \bar{R}_0[\mathbf{W}_F^T]_{ms} &= \bar{r}_s^T \bar{A} \bar{P}_{ms}
\end{aligned} \tag{E.15}$$

Derivation of Log-Linearized Equilibrium E.1 and Wedges E.2.

The log-linearized equilibrium sales, prices and output are derived by log-linearizing the results of Lemma D.1, D.2 and D.3. □

Derivation of Assumption 3.4 . Define $[\bar{\chi}]_k = (1 - \alpha_k \eta_k) \chi_k$. Assumption 3.4 formally implies the following. Let Δ_{PR} and Δ_{RP} be defined in (E.14) and let the parameter, $\bar{\chi}_k \forall k$, and the production structure be such that:

- (a) The direct effect of distortions on prices outweighs the counteracting indirect effect of distortions on prices via revenues.

$$0 < \sum_{m=1}^M [\Delta_{PR}]_{km} = \sum_{m=1}^M [\mathbf{W}_P^P]_{km} - \sum_{n=1}^M (1 - \bar{\chi}_n) [\mathbf{W}_P^P]_{kn} [\mathbf{W}_R^R]_{nm}$$

- (b) The direct effect of revenues on output outweighs the indirect effect of revenues on output via prices.

$$0 < \sum_{m=1}^M [\Delta_{RP}]_{km} = \sum_{m=1}^M [\mathbf{W}_R^R]_{km} - \sum_{n=1}^M (1 - \bar{\chi}_n) [\mathbf{W}_P^P]_{kn} [\mathbf{W}_R^R]_{nm}$$

□

Proof of Proposition 1. The credit wedges of revenues (E.7), prices (E.10) and output (E.13) can be decomposed into

$$\widehat{\phi}_k^\mathcal{V} = \begin{cases} (1) & \widehat{\phi}_m^L, \widehat{\phi}_{ms}^X \forall m, s & \text{direct and indirect upstream cost-effects} \\ (2) & \widehat{\phi}_{cm}^X \forall m, c & \text{direct and indirect downstream demand-effects} \\ (3) & \widehat{\phi}_m^R \forall m & \text{income effects from financial intermediation} \\ (4) & \widehat{\phi}_F^S & \text{final demand income effects} \end{cases}$$

for $\mathcal{V} \in \{S, P, Q, Y\}$. The respective wedge responses are defined Definition E.2. The first-order conditions imply that: (1) An increase in credit wedges of k 's supplier s affects s 's cost of production leading to an increase in the price charged on their output. (2) Similarly, an increase in credit wedges affecting sector k 's customer c increases c 's cost of production and therefore reduces the demand for k 's output. (3) An increase in the

revenue wedge of sector k increases it's income from extending trade credit for every output sold. (4) An increase in the final sales wedge decreases the income of households and therefore the demand for the final and subsequently for intermediate inputs.

In the following, I explicitly summarize and outline the components of (a) the intermediate ($\phi_{\kappa,k}^S$) and final sales wedge (ϕ_F^S) (b) the price wedge ($\phi_{\kappa,k}^P$) and (c) the output (ϕ_k^Q) using the results of Definition E.2.

(a) The intermediate and final sales wedge can be decomposed as follows

$$\hat{\phi}_{\kappa,k}^S = \begin{cases} (2) & + \sum_{c=1}^M [\mathbf{W}_R^X]_{ck} \hat{\phi}_{ck}^X \\ (3) & - \hat{\phi}_k^R \\ (4) & + [\mathbf{W}_R^F]_{kk} \hat{\phi}_F^S \end{cases} \quad \hat{\phi}_F^S = \begin{cases} (1a) & - \sum_{m=1}^M [\mathbf{W}_F^\phi]_m \hat{\phi}_m^L - \sum_{m=1}^M \sum_{s=1}^M [\mathbf{W}_F^\Phi]_{ms} \hat{\phi}_{ms}^X \\ (1b) & + \sum_{m=1}^M \sum_{s=1}^M [\mathbf{W}_F^T]_{ms} \hat{r}_s^T \\ (1c) & + \sum_{m=1}^M \sum_{s=1}^M [\mathbf{W}_F^\theta]_{ms} \hat{\theta}_{ms} \end{cases}$$

The respective coefficients are all positive and defined in derivation of Definition E.2.

(b) The price wedge can be decomposed as follows

$$\hat{\phi}_{\kappa,k}^P = \begin{cases} (1) & + \sum_{m=1}^M [\mathbf{W}_P^P]_{km} (1 - \alpha_m) \eta_m \chi_m \hat{\phi}_m^L + \sum_{m=1}^M \sum_{s=1}^M [\mathbf{W}_P^P]_{km} (1 - \eta_m) \chi_m \omega_{ms}^X \hat{\phi}_{ms}^X \\ (2) & - \sum_{m=1}^M \sum_{c=1}^M [\mathbf{W}_P^R]_{km} [\mathbf{W}_R^X]_{cm} \hat{\phi}_{cm}^X \\ (3) & - \sum_{m=1}^M ([\mathbf{W}_P^P]_{km} - [\mathbf{W}_P^R]_{km}) \hat{\phi}_m^R \\ (4) & - \sum_{m=1}^M [\mathbf{W}_P^R]_{km} [\mathbf{W}_R^F]_{mm} \hat{\phi}_F^S \end{cases}$$

All coefficients are defined in the derivation of Definition E.2 and - assuming that the demand structure is such that Assumption 3.4 holds - are non-negative.

(c) The real output wedge can be decomposed as follows

$$\widehat{\phi}_k^Q = \begin{cases} (1) & \sum_{m=1}^M [\mathbf{W}_P^P]_{km} (1 - \alpha_m) \eta_m \chi_m \widehat{\phi}_m^L + \sum_{m=1}^M \sum_{s=1}^M [\mathbf{W}_P^P]_{km} (1 - \eta_m) \chi_m \omega_{ms}^X \widehat{\phi}_{ms}^X \\ (2) & + \sum_{m=1}^M \sum_{c=1}^M ([\mathbf{W}_R^R]_{km} - [\mathbf{W}_P^R]_{km}) [\mathbf{W}_R^X]_{cm} \widehat{\phi}_{cm}^X \\ (3) & - \sum_{m=1}^M ([\mathbf{W}_P^P]_{km} + [\mathbf{W}_R^R]_{km} - [\mathbf{W}_P^R]_{km} - \mathcal{I}_{m=k}) \widehat{\phi}_m^R \\ (4) & + \sum_{m=1}^M ([\mathbf{W}_R^R]_{km} - [\mathbf{W}_P^R]_{km}) [\mathbf{W}_R^F]_{mm} \widehat{\phi}_F^S \end{cases}$$

All coefficients are defined derivation of Definition E.2 and are non-negative as outlined in Assumption 3.4. \square

E.2 Credit Wedges

Proof of Lemma 3.6. The log-linearization of the *revenue wedge* for sector k yields

$$\widehat{\phi}_k^R = [\mathbf{E}_{\phi(R)}^T]_{kk} \widehat{r}_k^T + \sum_{c=1}^M [\mathbf{E}_{\phi(R)}^\theta]_{ck} \widehat{\theta}_{ck} \quad (\text{E.16})$$

The *labor and intermediate credit wedge* deviations for each sector k are given by

$$\widehat{\phi}_k^L = [\mathbf{E}_{\phi(L)}^B]_{kk} \widehat{r}_k^B \quad \text{and} \quad \widehat{\phi}_{ks}^X = [\mathbf{E}_\Phi^B]_{ks} \widehat{r}_k^B + [\mathbf{E}_\Phi^T]_{ks} \widehat{r}_s^T - [\mathbf{E}_\Phi^\theta]_{ks} \widehat{\theta}_{ks} \quad (\text{E.17})$$

where the entries of the elasticity matrices are defined as follows

$$\begin{aligned} \overline{R}_k [\mathbf{E}_{\phi(R)}^T]_{kk} &= \overline{r}_k^T \overline{A} \overline{R}_k & \overline{\phi}_{ks}^X [\mathbf{E}_\Phi^B]_{ks} &= (1 - \overline{\theta}_{ks}) \overline{r}_k^B \\ \overline{R}_k [\mathbf{E}_{\phi(R)}^\theta]_{ck} &= \overline{r}_k^T \overline{A} \overline{R}_{ck} & \overline{\phi}_{ks}^X [\mathbf{E}_\Phi^T]_{ks} &= \overline{\theta}_{ks} \overline{r}_s^T \\ \overline{\phi}_k^L [\mathbf{E}_{\phi(L)}^B]_{kk} &= \overline{r}_k^B & \overline{\phi}_{ks}^X [\mathbf{E}_\Phi^\theta]_{ks} &= (\overline{r}_k^B - \overline{r}_s^T) \overline{\theta}_{ks} \end{aligned} \quad (\text{E.18})$$

The sign of the elasticity of the change in the trade credit share from sector k to sector s depends on the sign of the interest rate differential $\overline{\Delta}_{ks} = \overline{r}_k^B - \overline{r}_k^T$ and therefore can take on both positive and negative values. All remaining elasticities are positive. \square

Lemma E.1 (Sales Wedge). *The combined sales wedge ϕ_κ^S is defined in Equation (E.7) such that an increase in the combined sales wedge of sector k reduces sector k 's revenues. The wedge response can be written as*

$$\hat{\phi}_{\kappa,k}^S = - \sum_{m=1}^M [\mathbf{E}_{\phi(S)}^B]_{km} \hat{r}_m^B + \sum_{m=1}^M [\mathbf{E}_{\phi(S)}^T]_{km} \hat{r}_m^T + \sum_{m=1}^M \sum_{s=1}^M [\mathbf{E}_{\phi(S)}^\theta]_{k,ms} \hat{\theta}_{ms} \quad (\text{E.19})$$

The entries of the respective elasticity matrices are a combination of the elasticity matrices of the final and intermediate sales wedge. The elasticity of the sales wedge with respect to

- the bank interest rate of sector m is

$$[\mathbf{E}_{\phi(S)}^B]_{km} = \bar{r}_m^B [\mathbf{W}_{\phi(S)}^{B(L)}]_{km} \bar{w} \bar{\ell}_m^Q + \bar{r}_m^B \sum_{s=1}^M [\mathbf{W}_{\phi(S)}^{B(X)}]_{k,ms} \bar{A} \bar{P}_{ms}^-$$

- the trade credit interest rate of sector m is

$$[\mathbf{E}_{\phi(S)}^T]_{km} = \bar{r}_m^T \sum_{c=1}^M [\mathbf{W}_{\phi(S)}^{T(X)}]_{k,cm} \bar{A} \bar{R}_{cm}$$

- the trade credit share of sector m from sector s is

$$[\mathbf{E}_{\phi(S)}^\theta]_{k,ms} = [\mathbf{W}_{\phi(S)}^{\theta(X)}]_{k,ms} \bar{A} \bar{P}_{ms}$$

and the entries are defined as follows

$$\begin{aligned} [\mathbf{W}_{\phi(S)}^{B(L)}]_{km} &= \frac{\omega_k^F}{\bar{p} \bar{q}_k} \frac{1}{\bar{\phi}_m^L} \\ [\mathbf{W}_{\phi(S)}^{B(X)}]_{k,ms} &= \left\{ \frac{\omega_k^F}{\bar{p} \bar{q}_k} (1 + \bar{\theta}_{ms} \bar{r}_s^T) - \frac{\mathcal{I}_{s=k}}{\bar{p} \bar{q}_k} \right\} \frac{1}{\bar{\phi}_{ms}^X} \\ [\mathbf{W}_{\phi(S)}^{T(X)}]_{k,nm} &= \left\{ \frac{\omega_k^F}{\bar{p} \bar{q}_k} (1 - \bar{\theta}_{nm}) \bar{r}_n^B - \left(\frac{\bar{\phi}_{nm}^X - \bar{\phi}_m^R}{\bar{\phi}_m^R} \right) \frac{\mathcal{I}_{m=k}}{\bar{p} \bar{q}_m} \right\} \frac{1}{\bar{\phi}_{nm}^X} \\ [\mathbf{W}_{\phi(S)}^{\theta(X)}]_{k,ms} &= \left\{ \frac{\omega_k^F}{\bar{p} \bar{q}_k} \left[(1 + \bar{r}_s^T) \bar{r}_m^B + \bar{\Delta}_{ms} \frac{\bar{\phi}_{ms}^X}{\bar{\phi}_m^L} \right] - \left[\bar{r}_m^B + \bar{r}_s^T \left(\frac{\bar{\phi}_{ms}^X - \bar{\phi}_s^R}{\bar{\phi}_s^R} \right) \right] \frac{\mathcal{I}_{s=k}}{\bar{p} \bar{q}_k} \right\} \frac{1}{\bar{\phi}_{ms}^X} \end{aligned}$$

The sign of the respective entries are functions of the final demand structure such that $[\mathbf{W}_{\phi(S)}]_{ki}$ is positive if $(\omega_k^F \geq \bar{\omega}_k^F)$ and non-positive if $(\omega_k^F < \bar{\omega}_k^F)$, where

$$\bar{\omega}_k^F = \max \left\{ \frac{1}{1 + \bar{\theta}_{mk} \bar{r}_k^T}, \frac{1}{\bar{\phi}_c^R} \left[1 - \frac{\bar{r}_k^T}{\bar{r}_c^B} \frac{\bar{\theta}_k^C - \bar{\theta}_{ck}}{1 - \bar{\theta}_{ck}} \right], \left[\bar{r}_m^B + \bar{r}_k^T \left(\frac{\bar{\phi}_{mk}^X - \bar{\phi}_k^R}{\bar{\phi}_k^R} \right) \right] \left[(1 + \bar{r}_s^T) \bar{r}_m^B + \bar{\Delta}_{ms} \frac{\bar{\phi}_{ms}^X}{\bar{\phi}_m^L} \right]^{-1} \right\}$$

Proof of Lemma E.1. (a) The *FG-sales wedge*, ϕ_F^S , is defined in Equation (E.9). Using Equations (E.17), the wedge response can be written as

$$\widehat{\phi}_F^S = - \sum_{m=1}^M [\mathbf{e}_{\phi(S,F)}^B]_m \widehat{r}_m^B + \sum_{m=1}^M [\mathbf{e}_{\phi(S,F)}^T]_m \widehat{r}_m^T + \sum_{m=1}^M \sum_{s=1}^M [\mathbf{E}_{\phi(S,F)}^\theta]_{ms} \widehat{\theta}_{ms} \quad (\text{E.20})$$

The elasticities are given by

$$\begin{aligned} [\mathbf{e}_{\phi(S,F)}^B]_m &= \frac{\bar{r}_m^B}{\bar{R}_0} \left[\frac{1}{\bar{\phi}_m^L} \bar{w} \ell_m^Q + \sum_{s=1}^M \frac{(1 + \bar{\theta}_{ms} \bar{r}_s^T)}{\bar{\phi}_{ms}^X} \bar{A} \bar{P}_{ms}^- \right] \\ [\mathbf{e}_{\phi(S,F)}^T]_m &= \frac{\bar{r}_m^T}{\bar{R}_0} \sum_{n=1}^M \frac{(1 - \bar{\theta}_{nm}) \bar{r}_n^B}{\bar{\phi}_{nm}^X} \bar{A} \bar{R}_{nm} \\ [\mathbf{E}_{\phi(S,F)}^\theta]_{ms} &= \frac{1}{\bar{R}_0} \left[\frac{(1 + \bar{r}_s^T) \bar{r}_m^B}{\bar{\phi}_{ms}^X} + \frac{\bar{\Delta}_{ms}}{\bar{\phi}_m^L} \right] \bar{A} \bar{P}_{ms} \end{aligned}$$

Assuming that $(1 + \bar{r}_s^T)(1 + \bar{r}_m^B) \bar{r}_m^B > \bar{\Delta}_{ms} \bar{\phi}_{ms}^X$ holds, implies that all entries of the elasticity matrices are positive.

(b) The *IG-sales wedge* ϕ_X^S is defined in Equation (E.7). Using Equations (E.16) and (E.17), the wedge response can be written as

$$\widehat{\phi}_{X,k}^S = \sum_{c=1}^M [\mathbf{E}_{\phi(S,X)}^B]_{ck} \widehat{r}_c^B - [\mathbf{E}_{\phi(S,X)}^T]_{kk} \widehat{r}_k^T - \sum_{c=1}^M [\mathbf{E}_{\phi(S,X)}^\theta]_{ck} \widehat{\theta}_{ck} \quad (\text{E.21})$$

where

$$\begin{aligned} [\mathbf{E}_{\phi(S,X)}^B]_{ck} &= \bar{r}_c^B \frac{\bar{\phi}_k^R}{\bar{\phi}_{ck}^X} \frac{\bar{A} \bar{P}_{ck}^-}{\bar{R}_k}, \quad [\mathbf{E}_{\phi(S,X)}^T]_{kk} = \bar{r}_k^T \sum_{c=1}^M \left(1 - \frac{\bar{\phi}_k^R}{\bar{\phi}_{ck}^X} \right) \frac{\bar{A} \bar{R}_{ck}}{\bar{R}_k} \\ [\mathbf{E}_{\phi(S,X)}^\theta]_{ck} &= \left[\bar{r}_c^B \frac{\bar{\phi}_k^R}{\bar{\phi}_{ck}^X} + \bar{r}_k^T \left(1 - \frac{\bar{\phi}_k^R}{\bar{\phi}_{ck}^X} \right) \right] \frac{\bar{A} \bar{R}_{ck}}{\bar{R}_k} \end{aligned}$$

Note¹ that $0 < \bar{r}_c^B \bar{\phi}_k^R + \bar{r}_k^T (\bar{\phi}_{ck}^X - \bar{\phi}_k^R)$ holds if $\bar{r}_c^B [(1 + \bar{r}_k^T) + \bar{r}_k^T (\bar{\theta}_k^C - \bar{\theta}_{ck})] > LB$, where $LB = (\bar{r}_k^T)^2 (\bar{\theta}_k^C - \bar{\theta}_{ck})$. Therefore, all entries of the respective elasticity matrices are non-negative.

¹In addition, note that $\bar{\theta}_k^C < 1$ and

$$1 > \frac{\bar{\phi}_k^R}{\bar{\phi}_{ck}^X} = \frac{1 + \bar{r}_k^T \bar{\theta}_k^C}{1 + (1 - \bar{\theta}_{ck}) \bar{r}_c^B + \bar{\theta}_{ck} \bar{r}_k^T} \quad \text{holds if} \quad \frac{\bar{r}_c^B}{\bar{r}_k^T} > \frac{\bar{\theta}_k^C - \bar{\theta}_{ck}}{1 - \bar{\theta}_{ck}}$$

The latter inequality is trivially fulfilled if sector k supplies to one firm only such that $\bar{\theta}_k^C = \bar{\theta}_{ck}$.

(c) The *combined-sales wedge* ϕ_κ^S is defined in Equation (E.7). The log-linearized wedge is derived by combining the elasticity matrices of the final and intermediate sales wedge derived above. The response of sector k 's combined sales wedge depends on the demand structure in the economy: $\omega_k^F \in [0, 1]$:

- (1) ($\omega_k^F > 0$) - If sector k sells its output to the final good sector the final sales wedge also affects the combined sales wedge of sector k .
- (2) ($\omega_k^F = 0$) - If sector k does *not* sell its output to the final good sector, any changes in credit costs affecting the sales wedge and thus sales of the final good producer do not affect the sales wedge and thus sales of sector k .

□

Corollary E.1 (Total Sales Wedge). *Using the results of Lemma E.1 and collecting terms yields the response of the total sales wedge of sector k , ϕ_κ^S , defined in Equation (E.1):*

$$[\hat{\phi}_\kappa^R]_m = - \sum_{m=1}^M [\mathbf{E}_R^B]_{km} \hat{r}_m^B + \sum_{m=1}^M [\mathbf{E}_R^T]_{km} \hat{r}_m^T + \sum_{m=1}^M \sum_{s=1}^M [\mathbf{E}_R^\theta]_{k,ms} \hat{\theta}_{ms}$$

An increase in the total sales wedge of sector k reduces sector k 's revenues. The elasticity of the total sales wedge of sector k wrt changes in

- *the bank interest rate of sector m is*

$$[\mathbf{E}_R^B]_{km} = \bar{r}_m^B [\mathbf{W}_{R(R)}^{B(L)}]_{nm} \overline{w\ell}_m^Q + \bar{r}_m^B \sum_{s=1}^M [\mathbf{W}_{R(R)}^{B(X)}]_{n,ms} \overline{AP}_{ms}^-$$

- *the trade credit interest rate of sector m is*

$$[\mathbf{E}_R^T]_{km} = \bar{r}_m^T \sum_{c=1}^M [\mathbf{W}_{R(R)}^{T(X)}]_{k,cm} \overline{AR}_{cm}$$

- *the trade credit share of sector m from sector s is*

$$[\mathbf{E}_R^\theta]_{k,ms} = \sum_{n=1}^M [\mathbf{W}_{R(R)}^{\theta(X)}]_{k,ms} \overline{AP}_{ms}$$

Define $\mathbf{A}_v = \mathbf{W}_R^R$ for $v = R$. The respective entries of the coefficient matrices are given by

$$\begin{aligned} [\mathbf{W}_{R(R)}^{B(L)}]_{km} &= \left(\sum_{n=1}^M \omega_n^F \frac{[\mathbf{A}_R]_{kn}}{\bar{p}\bar{q}_n} \right) \frac{1}{\bar{\phi}_m^L} \\ [\mathbf{W}_{R(R)}^{B(X)}]_{k,ms} &= \left\{ \left(\sum_{n=1}^M \omega_n^F \frac{[\mathbf{A}_R]_{kn}}{\bar{p}\bar{q}_n} \right) (1 + \bar{\theta}_{ms} \bar{r}_s^T) - \frac{[\mathbf{W}_R^R]_{ks}}{\bar{p}\bar{q}_s} \right\} \frac{1}{\bar{\phi}_{ms}^X} \\ [\mathbf{W}_{R(R)}^{T(X)}]_{k,cm} &= \left\{ \left(\sum_{n=1}^M \omega_n^F \frac{[\mathbf{A}_R]_{kn}}{\bar{p}\bar{q}_n} \right) (1 - \bar{\theta}_{cm}) \bar{r}_c^B - \frac{[\mathbf{W}_R^R]_{km}}{\bar{p}\bar{q}_m} \left(\frac{\bar{\phi}_{cm}^X - \bar{\phi}_m^R}{\bar{\phi}_m^R} \right) \right\} \frac{1}{\bar{\phi}_{cm}^X} \\ [\mathbf{W}_{R(R)}^{\theta(X)}]_{k,ms} &= \left\{ \left(\sum_{n=1}^M \omega_n^F \frac{[\mathbf{A}_R]_{kn}}{\bar{p}\bar{q}_n} \right) \left[(1 + \bar{r}_s^T) \bar{r}_m^B + \bar{\Delta}_{ms} \frac{\bar{\phi}_{ms}^X}{\bar{\phi}_m^L} \right] - \frac{[\mathbf{W}_R^R]_{ks}}{\bar{p}\bar{q}_s} \left[\bar{r}_m^B + \bar{r}_s^T \left(\frac{\bar{\phi}_{ms}^X - \bar{\phi}_s^R}{\bar{\phi}_s^R} \right) \right] \right\} \frac{1}{\bar{\phi}_{ms}^X} \end{aligned}$$

Proof of Corollary E.1. Using Equation (E.1) and the results of Lemma E.1 yields the response of the total sales wedge of sector k . \square

Definition E.3 (Total Sales Wedges). Let the matrices $\mathbf{W}_{R(v)}^{B(L)}$, $\mathbf{W}_{R(v)}^{B(X)}$, $\mathbf{W}_{R(v)}^{T(X)}$ and $\mathbf{W}_{R(v)}^{\theta(X)}$ be defined in Corollary E.1. The subscript $R(v)$ for $v \in \{R, P, Q\}$ denotes the coefficient matrix summarizing the final demand effects on (R) revenues $\mathbf{A}_R = \mathbf{W}_R^R$, (P) prices $\mathbf{A}_P = \mathbf{W}_P^R$, and (Q) output $\mathbf{A}_Q = \Delta_{RP}$.

Lemma E.2 (Price Wedge). The combined price wedge $\hat{\phi}_\kappa^P$ is defined in Equation (E.10) and is a combination of the price wedge (E.11) and the combined sales wedge (E.7) due to the presence of decreasing returns to scale such that prices are increasing in revenues. The wedge response in terms of the cost of credit can be written as

$$\phi_{\kappa,k}^P = \sum_{m=1}^M [\mathbf{E}_{\phi(P)}^B]_{km} \hat{r}_m^B + \sum_{m=1}^M [\mathbf{E}_{\phi(P)}^T]_{km} \hat{r}_m^T - \sum_{m=1}^M \sum_{s=1}^M [\mathbf{E}_{\phi(P)}^\theta]_{k,ms} \hat{\theta}_{ms} \quad (\text{E.22})$$

The typical entries of the elasticity matrices are derived below. The elasticity of the price wedge with respect to

- the interest rate on bank credit is

$$[\mathbf{E}_{\phi(P)}^B]_{km} = \bar{r}_m^B [\mathbf{W}_{\phi(P)}^{B(L)}]_{km} \bar{w}\bar{\ell}_m^Q + \bar{r}_m^B \sum_{s=1}^M [\mathbf{W}_{\phi(P)}^{B(X)}]_{k,ms} \bar{A}\bar{P}_{ms}^-$$

- the interest rate on trade credit

$$[\mathbf{E}_{\phi(P)}^T]_{km} = \bar{r}_m^T \sum_{c=1}^M [\mathbf{W}_{\phi(P)}^{T(X)}]_{k,cm} \bar{A}\bar{R}_{cm}$$

- the trade credit share of sector m obtained from sector s is

$$[\mathbf{E}_{\phi(P)}^\theta]_{k,ms} = [\mathbf{W}_{\phi(P)}^{\theta(X)}]_{k,ms} \overline{AP}_{ms}$$

The respective entries of the coefficient matrices are given by

$$\begin{aligned} [\mathbf{W}_{\phi(P)}^{B(L)}]_{km} &= \frac{[\mathbf{W}_P^P]_{km}}{\overline{R}_m} + [\mathbf{W}_{R(P)}^{B(L)}]_{km} \quad , \quad [\mathbf{W}_{\phi(P)}^{B(X)}]_{k,ms} = \frac{[\mathbf{W}_P^P]_{km}}{\overline{R}_m} + [\mathbf{W}_{R(P)}^{B(X)}]_{k,ms} \\ [\mathbf{W}_{\phi(P)}^{T(X)}]_{k,cm} &= \frac{[\mathbf{W}_P^P]_{kc}}{\overline{R}_c} - \frac{[\mathbf{W}_P^P]_{km}}{\overline{R}_m} - [\mathbf{W}_{R(P)}^{T(X)}]_{k,cm} \\ [\mathbf{W}_{\phi(P)}^{\theta(X)}]_{k,ms} &= \frac{[\mathbf{W}_P^P]_{ks}}{\overline{R}_s} \bar{r}_s^T + \frac{[\mathbf{W}_P^P]_{km}}{\overline{R}_m} (\bar{r}_m^B - \bar{r}_s^T) + [\mathbf{W}_{R(P)}^{\theta(X)}]_{k,ms} \end{aligned}$$

The weight matrices $(\mathbf{W}_{R(P)})$ capturing the effect of revenues on prices are defined in Definition E.3.

Proof of Lemma E.2. Using Equations (E.17) and (E.16), the price wedge response as given by Equation (E.11) can be written as

$$\hat{\phi}_{P,k}^P = [\mathbf{E}_{\phi(P,P)}^B]_{kk} \hat{r}_k^B + \sum_{s=1}^M [\mathbf{E}_{\phi(P,P)}^T]_{ks} \hat{r}_s^T - \sum_{s=1}^M [\mathbf{E}_{\phi(P,P)}^{\theta(S)}]_{ks} \hat{\theta}_{ks} - \sum_{c=1}^M [\mathbf{E}_{\phi(P,P)}^{\theta(C)}]_{ck} \hat{\theta}_{ck} \quad (\text{E.23})$$

The typical entries of the corresponding elasticity matrices are defined below

$$\begin{aligned} 0 < [\mathbf{E}_{\phi(P,P)}^B]_{kk} &= \frac{\bar{r}_k^B}{\overline{R}_k} \left[w \bar{\ell}_k^Q + \sum_{n=1}^M \overline{AP}_{kn}^- \right] \\ 0 < [\mathbf{E}_{\phi(P,P)}^T]_{ks} &= \bar{r}_s^T \frac{\overline{AP}_{ks}}{\overline{R}_k} \quad \text{and} \quad 0 \geq [\mathbf{E}_{\phi(P,P)}^T]_{kk} = -\bar{r}_k^T \frac{(\overline{AR}_k - \overline{AR}_{kk})}{\overline{R}_k} \\ 0 \leq [\mathbf{E}_{\phi(P,P)}^{\theta(S)}]_{ks} &= (\bar{r}_k^B - \bar{r}_s^T) \frac{\overline{AP}_{ks}}{\overline{R}_k} \quad \text{and} \quad 0 < [\mathbf{E}_{\phi(P,P)}^{\theta(C)}]_{ck} = \bar{r}_k^T \frac{\overline{AR}_{ck}}{\overline{R}_k} \end{aligned}$$

The combined price wedge $\hat{\phi}_\kappa^P$ is defined in Equation (E.10) and is a combination of the price wedge (E.11) derived above and the combined (total) sales wedge (E.7) derived in Lemma E.1 and Corollary E.1. Straight forward calculations yield the results of Lemma E.2. \square

Lemma E.3 (Output Wedge). *The sectoral output wedge $\widehat{\phi}^Q$ is a combination of the sales (E.7), the revenue (E.16) and the price wedges (E.10) and can be written as*

$$\widehat{\phi}_k^Q = \sum_{m=1}^M [\mathbf{E}_{\phi(Q)}^B]_{km} \widehat{r}_m^B + \sum_{m=1}^M [\mathbf{E}_{\phi(Q)}^T]_{km} \widehat{r}_m^T - \sum_{m=1}^M \sum_{s=1}^M [\mathbf{E}_{\phi(Q)}^\theta]_{k,ms} \widehat{\theta}_{ms} \quad (\text{E.24})$$

The elasticity of the output wedge of sector k wrt to changes in

- *the bank interest rate is*

$$[\mathbf{E}_{\phi(Q)}^B]_{km} = \bar{r}_m^B [\mathbf{W}_Q^{B(L)}]_{km} \overline{w\ell}_m^Q + \bar{r}_m^B \sum_{s=1}^M [\mathbf{W}_Q^{B(X)}]_{k,ms} \overline{AP}_{ms}^-$$

- *the trade credit interest rate is*

$$[\mathbf{E}_{\phi(Q)}^T]_{km} = \bar{r}_m^T \sum_{c=1}^M [\mathbf{W}_Q^{T(X)}]_{k,cm} \overline{AR}_{cm}$$

- *the trade credit shares is*

$$[\mathbf{E}_{\phi(Q)}^\theta]_{k,ms} = [\mathbf{W}_Q^{\theta(X)}]_{k,ms} \overline{AP}_{ms}$$

The respective coefficient matrices are given by

$$\begin{aligned} [\mathbf{W}_Q^{B(L)}]_{km} &= \frac{[\mathbf{W}_P^P]_{km}}{\bar{R}_m} - [\mathbf{W}_{R(Q)}^{B(L)}]_{km} \quad , \quad [\mathbf{W}_Q^{B(X)}]_{k,ms} = \frac{[\mathbf{W}_P^P]_{km}}{\bar{R}_m} - [\mathbf{W}_{R(Q)}^{B(X)}]_{k,ms} \\ [\mathbf{W}_Q^{T(X)}]_{k,cm} &= \frac{\mathcal{I}_{m=k}}{\bar{R}_m} + \frac{[\mathbf{W}_P^P]_{kc}}{\bar{R}_c} - \frac{[\mathbf{W}_P^P]_{km}}{\bar{R}_m} + [\mathbf{W}_{R(Q)}^{T(X)}]_{k,cm} \\ [\mathbf{W}_Q^{\theta(X)}]_{k,ms} &= \frac{[\mathbf{W}_P^P]_{km}}{\bar{R}_m} (\bar{r}_m^B - \bar{r}_s^T) + \frac{([\mathbf{W}_P^P]_{ks} - \mathcal{I}_{s=k})}{\bar{R}_s} \bar{r}_s^T - [\mathbf{W}_{R(Q)}^{\theta(X)}]_{k,ms} \end{aligned}$$

The weight matrices ($\mathbf{W}_{R(Q)}$) capturing the effect of revenues on output are defined in Definition E.3. An increase in the output wedge of sector k reduces sector k 's output.

Proof of Lemma E.3. The sectoral output wedge $\widehat{\phi}^Q$ is a combination of the sales (E.7), the revenue (E.16) and the price wedges (E.10). Using the results of Lemma 3.6, E.1 and E.2, Lemma E.3 follows from straight forward calculations. □

E.3 Credit Costs, Links and Interest Rates

Credit Management Costs. The log-linearization of *total management credit costs* for sector k can be written as

$$\widehat{C}_k^T = \sum_{s=1}^M [\mathbf{E}_{C(T)}^\theta]_{ks} \widehat{\theta}_{ks} \quad (\text{E.25})$$

The typical entry of the elasticity matrix equals

$$\overline{C}_k^T [\mathbf{E}_{C(T)}^\theta]_{ks} = \kappa_{0,ks}^T \overline{\theta}_{ks}^\kappa + \kappa_{1,ks}^T \left(\frac{\overline{\theta}_{ks} - \overline{\theta}_k^S}{\overline{\theta}_k^S} \right) \frac{\overline{\theta}_{ks}}{\overline{\theta}_k^S} = \frac{\overline{\Delta}_{ks} \overline{AP}_{ks}}{1 + \overline{r}_k^B} \quad (\text{E.26})$$

where the last line exploits Equation (3.22), depicting the equilibrium trade credit share. The sign of the change in credit management costs depends on the sign of $[\mathbf{E}_{C(T)}^\theta]_{ks}$ which is a function of $\{\kappa_{0,ks}^T, \kappa_{1,ks}^T\}$ and $(\overline{\theta}_{ks} - \overline{\theta}_k^S)$.

Lemma E.4 (Trade Credit Share). *The log-linearization of the trade credit share between sector k and s defined in Equation (3.22) yields*

$$\widehat{\theta}_{ks} = + \sum_{m=1}^M [\mathbf{E}_\theta^B]_{ks,m} \widehat{r}_m^B - \sum_{m=1}^M [\mathbf{E}_\theta^T]_{ks,m} \widehat{r}_m^T - \sum_{m=1}^M \sum_{n=1}^M [\mathbf{E}_\theta^\theta]_{ks,mn} \widehat{\theta}_{mn} \quad (\text{E.27})$$

The response of the trade credit share is a function of the response of the interest rate on bank and trade credit derived in Lemma E.5 and the total sales wedge derived in Corollary E.1. The elasticity of trade credit share wrt to changes in

- the bank interest rate of sector m is

$$[\mathbf{E}_\theta^B]_{ks,m} = \overline{r}_m^B \left\{ [\mathbf{W}_\theta^{B(\theta)}]_{ks,k} \mathcal{I}_{m=k} + [\mathbf{W}_\theta^{B(L)}]_{ks,m} \overline{w} \ell_m^Q + \sum_{s=1}^M [\mathbf{W}_\theta^{B(X)}]_{ks,ms} \overline{AP}_{ms}^- \right\}$$

- the trade credit interest rate of sector m is

$$[\mathbf{E}_\theta^T]_{ks,m} = \overline{r}_m^T \left\{ [\mathbf{W}_\theta^{T(\theta)}]_{ks,m} \mathcal{I}_{m=s} + [\mathbf{W}_\theta^{T(X)}]_{ks,cm} \overline{AR}_{cm} \right\}$$

- the trade credit share is

$$[\mathbf{E}_\theta^\theta]_{ks,ms} = \sum_{n=1}^M [\mathbf{W}_\theta^{\theta(X)}]_{ks,ms} \overline{AP}_{ms}$$

Defining

$$[\mathcal{K}_\theta^R]_{ks} = \text{sgn}(\bar{\Delta}_{ks}) \left| \frac{\bar{\Delta}_{ks}}{[\mathcal{K}_\theta]_{ks}} \right|, \text{ where } 0 < [\mathcal{K}_\theta]_{ks} = \bar{\Delta}_{ks} \left[\frac{\bar{\theta}_{ks}}{\bar{\theta}_{ks} - \bar{\theta}_{ks}^\kappa} - \bar{\Delta}_{ks} \frac{\bar{\theta}_{ks}}{\bar{\phi}_{ks}^X} \right]$$

the respective entries of the coefficient matrices are given by

$$\begin{aligned} [\mathbf{W}_\theta^{B(\theta)}]_{ks,k} &= [\mathcal{K}_\theta]_{ks}^{-1} \left\{ 1 - \bar{\Delta}_{ks} \left[\frac{(1 - \bar{\theta}_{ks})}{\bar{\phi}_{ks}^X} + \frac{1}{\bar{\phi}_k^L} \right] \right\}, & [\mathbf{W}_\theta^{T(\theta)}]_{ks,m} &= [\mathcal{K}_\theta]_{ks}^{-1} \left\{ 1 - \bar{\Delta}_{ks} \frac{\bar{\theta}_{ks}}{\bar{\phi}_{ks}^X} \right\} \\ [\mathbf{W}_\theta^{B(L)}]_{ks,m} &= [\mathcal{K}_\theta^R]_{ks} [\mathbf{W}_{R(R)}^{B(L)}]_{km}, & [\mathbf{W}_\theta^{T(X)}]_{ks,cm} &= [\mathcal{K}_\theta^R]_{ks} [\mathbf{W}_{R(R)}^{T(X)}]_{k,cm} \\ [\mathbf{W}_\theta^{B(X)}]_{ks,ms} &= [\mathcal{K}_\theta^R]_{ks} [\mathbf{W}_{R(R)}^{B(X)}]_{k,ms}, & [\mathbf{W}_\theta^{\theta(X)}]_{ks,ms} &= [\mathcal{K}_\theta^R]_{ks} [\mathbf{W}_{R(R)}^{\theta(X)}]_{k,ms} \end{aligned}$$

and the weight matrix capturing the effect of revenues is defined in Corollary E.1.

Proof of Lemma E.4. Lemma E.4 follows from the log-linearization of Equation (3.22), tedious algebra and applying the results of Corollary E.1. \square

Lemma E.5 (Interest Rates). *The log-linearization of the interest rate on bank credit defined in Equation (3.8) yields*

$$\hat{r}_k^B = [\mathbf{E}_B^{Z_b}]_{kk} \hat{z}_k^b + \sum_c [\mathbf{E}_B^\theta]_{ck} \hat{\theta}_{ck} \quad (\text{E.28})$$

Defining $\bar{r}_k^Z = \bar{r}_k^B - \bar{x}_0^B$, and $\bar{\theta}_k^Z = \bar{\theta}_0^D + \bar{\theta}_k^C$, the relevant entries of the elasticity matrices are positive and given by

$$\bar{r}_k^B [\mathbf{E}_B^{Z_b}]_{kk} = \bar{r}_k^Z \quad \text{and} \quad \bar{r}_k^B [\mathbf{E}_B^\theta]_{ck} = \frac{\mu \bar{r}_k^Z \bar{A} \bar{R}_{ck}}{\bar{\theta}_k^Z \bar{p}_k \bar{q}_k}$$

The log-linearization of the interest rate on trade credit in Equation (3.24) yields

$$\hat{r}_k^T = - \sum_{m=1}^M [\mathbf{E}_T^B]_{km} \hat{r}_m^B + \sum_{m=1}^M [\mathbf{E}_T^T]_{km} \hat{r}_m^T + \sum_{m=1}^M \sum_{n=1}^M [\mathbf{E}_T^\theta]_{k,mn} \hat{\theta}_{mn} + [\mathbf{E}_T^{Z_b}]_{kk} \hat{z}_k^b \quad (\text{E.29})$$

The elasticity of the interest rate on trade credit with respect to

- the shock to the bank risk premium

$$[\mathbf{E}_T^{Z_b}]_{km} = \bar{\phi}_k^R$$

the interest rate on bank credit is

$$[\mathbf{E}_T^B]_{km} = \bar{r}_m^B [\mathbf{W}_T^{B(L)}]_{km} \bar{w} \ell_m^Q + \bar{r}_m^B \sum_{s=1}^M [\mathbf{W}_T^{B(X)}]_{k,ms} \bar{A} \bar{P}_{ms}^-$$

- the interest rate on trade credit is

$$[\mathbf{E}_T^T]_{km} = \bar{r}_m^T \sum_{c=1}^M [\mathbf{W}_T^{T(X)}]_{k,cm} \bar{A} \bar{R}_{cm}$$

- the trade credit share of sector m from sector s is

$$[\mathbf{E}_T^\theta]_{k,ms} = [\mathbf{W}_T^\theta]_{k,ms} \bar{A} \bar{P}_{ms}$$

The entries of the coefficient matrices are

$$\begin{aligned} [\mathbf{W}_T^{B(L)}]_{km} &= \left\{ \frac{\mathcal{I}_{m=k}}{\bar{\phi}_m^L} + \bar{B} \bar{C}_k^T [\mathbf{W}_{R(R)}^{B(L)}]_{km} \right\} \frac{\bar{\phi}_k^R}{\bar{B} \bar{C}_k} \\ [\mathbf{W}_T^{B(X)}]_{k,ms} &= \left\{ \frac{(1 - \bar{\theta}_{ks})}{\bar{\phi}_{ms}^X} \mathcal{I}_{m=k} + \bar{B} \bar{C}_k^T [\mathbf{W}_{R(R)}^{B(X)}]_{k,ms} \right\} \frac{\bar{\phi}_k^R}{\bar{B} \bar{C}_k}, \\ [\mathbf{W}_T^{T(X)}]_{k,cm} &= \left\{ \frac{(1 - \bar{\theta}_{km})}{\bar{\phi}_{cm}^X} \mathcal{I}_{c=k} - \bar{B} \bar{C}_k^T [\mathbf{W}_{R(R)}^{T(X)}]_{k,cm} \right\} \frac{\bar{\phi}_k^R}{\bar{B} \bar{C}_k}. \end{aligned}$$

where $\bar{B} \bar{C}_k = \bar{B} \bar{C}_k^Q + \bar{B} \bar{C}_k^T$ and $\bar{B} \bar{C}_k^T = w \ell_k^T$.

The entries of the coefficient matrix related to the trade credit shares can be decomposed into $[\mathbf{W}_T^\theta]_{k,ms} = [\mathbf{W}_T^{\theta(C)}]_{k,ms} \mathcal{I}_{s=k} + [\mathbf{W}_T^{\theta(S)}]_{k,ms} \mathcal{I}_{m=k} + [\mathbf{W}_T^{\theta(R)}]_{k,ms}$ where

$$\begin{aligned} [\mathbf{W}_T^{\theta(C)}]_{k,ck} &= \left[\frac{(\mu - 1)}{\bar{\theta}_k^Z} + \bar{r}_k^T \frac{\bar{\theta}_0^D + \mu \bar{\theta}_k^C}{\bar{\theta}_k^Z} \right] \frac{1}{p q_k}, \quad [\mathbf{W}_T^{\theta(S)}]_{k,ks} = \left[(1 - \bar{\theta}_{ks}) + \frac{\bar{\phi}_{ks}^X}{\bar{\phi}_k^L} \right] \frac{\bar{\Delta}_{ks}}{\bar{\phi}_{ks}^X} \frac{\bar{\phi}_k^R}{\bar{B} \bar{C}_k}, \text{ and} \\ [\mathbf{W}_T^{\theta(R)}]_{k,ms} &= \bar{B} \bar{C}_k^T [\mathbf{W}_{R(R)}^{\theta(X)}]_{k,ms} \frac{\bar{\phi}_k^R}{\bar{B} \bar{C}_k}. \end{aligned}$$

The weight matrices capturing the effect of revenues are defined in Corollary E.1.

Proof of Lemma E.5. Using the results of Corollary E.1, Lemma E.5 follows from the log-linearization of the *interest rate on bank credit* in Equation (3.8) and on *trade credit* in Equation (3.24). \square

E.4 Partial Equilibrium Structural Credit Response

Derivation of Credit Multiplier 3.4. In partial equilibrium assume that $\widehat{L} = 0$ and abstract for changes in quantity shares, $w_{ck}^X = x_{ck}(q_k)^{-1}$, such that $[\widehat{w}^X]_{ck} = 0 \forall c, k$. Using the results of Lemma E.4 and E.5, the responses of credit-costs and shares to financial shocks, $\widehat{z}_k^b = \epsilon_k^b$, are given by

$$\begin{aligned}\widehat{r}_k^B &= + \sum_{c=1}^M [\mathbf{E}_B^\theta]_{ck} \widehat{\theta}_{ck} + [\mathbf{E}_B^{Z_b}]_{kk} \widehat{z}_k^b \\ \widehat{r}_k^T &= - \sum_{m=1}^M [\mathbf{E}_T^B]_{km} \widehat{r}_m^B + \sum_{m=1}^M [\mathbf{E}_T^T]_{km} \widehat{r}_m^T + \sum_{m=1}^M \sum_{n=1}^M [\mathbf{E}_T^\theta]_{k,mn} \widehat{\theta}_{mn} + [\mathbf{E}_T^{Z_b}]_{kk} \widehat{z}_k^b \\ \widehat{\theta}_e &= + \sum_{m=1}^M [\mathbf{E}_\theta^B]_{em} \widehat{r}_m^B - \sum_{m=1}^M [\mathbf{E}_\theta^T]_{em} \widehat{r}_m^T - \sum_{m=1}^M \sum_{n=1}^M [\mathbf{E}_\theta^\theta]_{e,mn} \widehat{\theta}_{mn}\end{aligned}$$

Define the vector of changes in credit costs and shares as $\boldsymbol{\tau} = [\widehat{\mathbf{r}}^B, \widehat{\mathbf{r}}^T, \widehat{\boldsymbol{\theta}}]$, where the vector of trade credit shares is $\boldsymbol{\theta} = \text{vec}(\boldsymbol{\Theta})$. Then stacking yields

$$\begin{bmatrix} \widehat{\mathbf{r}}^B \\ \widehat{\mathbf{r}}^T \\ \widehat{\boldsymbol{\theta}} \end{bmatrix} = \begin{bmatrix} \mathbf{0} & \mathbf{0} & +\mathring{\mathbf{E}}_B^\theta \\ -\mathbf{E}_T^B & +\mathbf{E}_T^T & +\mathring{\mathbf{E}}_T^\theta \\ +\mathring{\mathbf{E}}_\theta^B & -\mathring{\mathbf{E}}_\theta^T & -\mathring{\mathbf{E}}_\theta^\theta \end{bmatrix} \begin{bmatrix} \widehat{\mathbf{r}}^B \\ \widehat{\mathbf{r}}^T \\ \widehat{\boldsymbol{\theta}} \end{bmatrix} + \begin{bmatrix} +\mathbf{E}_B^{Z_b} \\ +\mathbf{E}_T^{Z_b} \\ \mathbf{0} \end{bmatrix} \boldsymbol{\epsilon}_b \Bigg\} \boldsymbol{\tau} = \mathbf{E}_\tau^\tau \boldsymbol{\tau} + \mathbf{E}_\tau^{Z_b} \boldsymbol{\epsilon}_b$$

and the corresponding elasticity matrices, $\mathring{\mathbf{E}}_\theta^B$, $\mathring{\mathbf{E}}_\theta^T$, and $\mathring{\mathbf{E}}_\theta^\theta$ are of size $(T \times M)$, $(M \times T)$ and $(T \times T)$, respectively, for $T = M^2$. Furthermore, follow Definition 3.2 and let E denote the cardinality of the edge set \mathcal{E} indexed by $e = 1, \dots, E$. The credit multiplier is given by the first order approximation of

$$\boldsymbol{\Psi}_\tau = (\mathbf{I} - \mathbf{E}_\tau^\tau)^{-1} = \begin{bmatrix} \boldsymbol{\Psi}_\tau^{BB} & \boldsymbol{\Psi}_\tau^{BT} & \boldsymbol{\Psi}_\tau^{B\theta} \\ \boldsymbol{\Psi}_\tau^{TB} & \boldsymbol{\Psi}_\tau^{TT} & \boldsymbol{\Psi}_\tau^{T\theta} \\ \boldsymbol{\Psi}_\tau^{\theta B} & \boldsymbol{\Psi}_\tau^{\theta T} & \boldsymbol{\Psi}_\tau^{\theta\theta} \end{bmatrix} \approx \widetilde{\boldsymbol{\Psi}}_\tau = \mathbf{I} + \mathbf{E}_\tau^\tau.$$

□

Proof of Proposition 2. Applying Definition 3.4, the responses of credit-costs and shares to *credit* shocks $\widehat{z}_k^b = \epsilon_k^b$ are can be written in matrix form as

$$\begin{bmatrix} \widehat{\mathbf{r}}^B \\ \widehat{\mathbf{r}}^T \\ \widehat{\boldsymbol{\theta}} \end{bmatrix} = + \begin{bmatrix} \boldsymbol{\Psi}_\tau^{BB} \mathbf{E}_B^{Z_b} + \boldsymbol{\Psi}_\tau^{BT} \mathbf{E}_T^{Z_b} \\ \boldsymbol{\Psi}_\tau^{TB} \mathbf{E}_B^{Z_b} + \boldsymbol{\Psi}_\tau^{TT} \mathbf{E}_T^{Z_b} \\ \boldsymbol{\Psi}_\tau^{\theta B} \mathbf{E}_B^{Z_b} + \boldsymbol{\Psi}_\tau^{\theta T} \mathbf{E}_T^{Z_b} \end{bmatrix} \boldsymbol{\epsilon}_b \approx \begin{bmatrix} \widetilde{\boldsymbol{\Psi}}_\tau^B \\ \widetilde{\boldsymbol{\Psi}}_\tau^T \\ \widetilde{\boldsymbol{\Psi}}_\tau^\theta \end{bmatrix} \boldsymbol{\epsilon}_b$$

The *first order approximation* of the PE-credit multiplier Ψ_τ and using the results of Lemma E.4 and E.5, implies that the first order approximation of the responses of

(a) the interest rate on bank credit is $[\tilde{r}^B]_k = \sum_{m=1}^M [\tilde{\Psi}_\tau^B]_{km} \epsilon_m^b$, where

$$[\tilde{\Psi}_\tau^B]_{km} = [\mathbf{E}_B^{Z_b}]_{mm} \mathcal{I}_{m=k}$$

(b) the interest rate on trade credit is $[\tilde{r}^T]_k = \sum_{m=1}^M [\tilde{\Psi}_\tau^T]_{km} \epsilon_m^b$, where

$$\begin{aligned} [\tilde{\Psi}_\tau^T]_{km} = & +[\mathbf{E}_T^{Z_b}]_{mm} \mathcal{I}_{m=k} + \bar{r}_m^T [\mathbf{E}_T^{Z_b}]_{mm} \sum_{c=1}^M [\mathbf{W}_T^{T(X)}]_{k,cm} \overline{AR}_{cm} \\ & - \bar{r}_m^B [\mathbf{E}_B^{Z_b}]_{mm} \left\{ [\mathbf{W}_T^{B(L)}]_{km} \overline{w\ell}_m^Q + \sum_{s=1}^M [\mathbf{W}_T^{B(X)}]_{k,ms} \overline{AP}_{ms}^- \right\} \end{aligned}$$

(c) the trade credit share for $e = ks$ is $[\tilde{\theta}]_e = \sum_{m=1}^M [\tilde{\Psi}_\tau^\theta]_{em} \epsilon_m^b$, where

$$\begin{aligned} [\tilde{\Psi}_\tau^\theta]_{em} = & +\bar{r}_m^B [\mathbf{E}_B^{Z_b}]_{mm} \left\{ [\mathbf{W}_\theta^{B(\theta)}]_{ek} \mathcal{I}_{m=k} + [\mathbf{W}_\theta^{B(L)}]_{em} \overline{w\ell}_m^Q + \sum_{s=1}^M [\mathbf{W}_\theta^{B(X)}]_{e,ms} \overline{AP}_{ms}^- \right\} \\ & - \bar{r}_m^T [\mathbf{E}_T^{Z_b}]_{mm} \left\{ [\mathbf{W}_\theta^{T(\theta)}]_{em} \mathcal{I}_{m=s} + \sum_{c=1}^M [\mathbf{W}_\theta^{T(X)}]_{e,cm} \overline{AR}_{cm} \right\} \end{aligned}$$

The existence of trade credit links therefore implies that credit costs are linked and that financial shocks to the cost of bank credit are passed on through the IO-network via payment schedules (both up- and downstream). Note that productivity shocks enter only via the effect on the aggregate price-index on final demand and thus aggregate labor, which I have abstracted from. \square

E.5 Partial Equilibrium Structural Output Response

Proof of Proposition 3. (a) Consider the partial equilibrium in Definition 3.4 and let the response of the interest rate on bank and trade credit and trade credit shares be given in Equation (3.29) in the absence of productivity shocks, $\widehat{z}_k^q = \epsilon_k^q = 0$. Using Equation (E.5) and applying the first order approximation of the trade credit multiplier derived in Definition 4.2, the output (wedge) response to a first order approximation is given by

$$\tilde{q}_k = - \sum_{m=1}^M \left\{ [\tilde{\mathbf{S}}_Q^B]_{km} + [\tilde{\mathbf{S}}_Q^T]_{km} - [\tilde{\mathbf{S}}_Q^\theta]_{km} \right\} \epsilon_m^b = - \sum_{m=1}^M [\tilde{\mathbf{S}}_B^Q]_{km} \epsilon_m^b$$

where

$$[\tilde{\mathbf{S}}_Q^B]_{km} = \sum_{n=1}^M [\mathbf{E}_{\phi(Q)}^B]_{kn} [\tilde{\Psi}_\tau^B]_{nm}, \quad [\tilde{\mathbf{S}}_Q^T]_{km} = \sum_{n=1}^M [\mathbf{E}_{\phi(Q)}^T]_{kn} [\tilde{\Psi}_\tau^T]_{nm}, \quad \text{and} \quad [\tilde{\mathbf{S}}_Q^\theta]_{km} = \sum_{e=1}^E [\mathbf{E}_{\phi(Q)}^\theta]_{ke} [\tilde{\Psi}_\tau^\theta]_{em}$$

Defining $[\tilde{\mathbf{S}}_{B,B}^Q]_{km} = [\tilde{\mathbf{S}}_Q^B]_{km}$ and $[\tilde{\mathbf{S}}_{B,T}^Q]_{km} = [\tilde{\mathbf{S}}_Q^T]_{km} - [\tilde{\mathbf{S}}_Q^\theta]_{km}$ completes the proof of the first part of Proposition 3.

(b) Following Definition 3.2, E denotes the cardinality of the edge set \mathcal{E} indexed by $e = 1, \dots, E$. Straight forward but tedious algebra yields the first order approximation of the structural coefficients related to the interest rate on bank, $[\tilde{\mathbf{S}}_Q^B]_{km}$, and trade credit, $[\tilde{\mathbf{S}}_Q^T]_{km}$, and trade credit shares, $[\tilde{\mathbf{S}}_Q^\theta]_{km}$, where the respective entries of the elasticities matrices are defined in Lemma E.3, E.4 and E.5. Combining the results of (b) with the structural credit elasticities derived in Proposition 2, collecting terms and defining the structural elasticities

$$[\mathbf{S}_{Q,B}^{B(L)}]_{km} = [\mathbf{W}_Q^{B(L)}]_{km} \quad \text{and} \quad [\mathbf{S}_{Q,B}^{B(X)}]_{k,ms} = [\mathbf{W}_Q^{B(X)}]_{k,ms} \quad (\text{E.30})$$

as well as

$$\begin{aligned} [\mathbf{S}_{Q,T}^{B(L)}]_{k,ms} &= \left(\sum_{n=1}^M [\mathbf{E}_{\phi(Q)}^T]_{kn} [\mathbf{W}_T^{B(L)}]_{nm} \right) + \left(\sum_{e=1}^E [\mathbf{E}_{\phi(Q)}^\theta]_{ke} [\mathbf{W}_\theta^{B(L)}]_{em} \right) \\ [\mathbf{S}_{Q,T}^{B(X)}]_{k,ms} &= \left(\sum_{n=1}^M [\mathbf{E}_{\phi(Q)}^T]_{kn} [\mathbf{W}_T^{B(X)}]_{n,ms} \right) + \left(\sum_{e=1}^E [\mathbf{E}_{\phi(Q)}^\theta]_{ke} [\mathbf{W}_\theta^{B(X)}]_{e,ms} \right) \\ [\mathbf{S}_{Q,T}^{T(X)}]_{k,cm} &= [\mathbf{W}_Q^{T(X)}]_{k,cm} + \left(\sum_{n=1}^M [\mathbf{E}_{\phi(Q)}^T]_{kn} [\mathbf{W}_T^{T(X)}]_{n,cm} \right) + \left(\sum_{e=1}^E [\mathbf{E}_{\phi(Q)}^\theta]_{ke} [\mathbf{W}_\theta^{T(X)}]_{e,cm} \right) \quad (\text{E.31}) \\ [\mathbf{S}_{Q,T}^{B(\theta)}]_{km} &= \sum_{s=1}^M [\mathbf{W}_Q^{\theta(X)}]_{k,ms} [\mathbf{W}_\theta^{B(\theta)}]_{ms,m} \frac{\overline{AP}_{ms}}{w\ell_m^T} \\ [\mathbf{S}_{Q,T}^{T(\theta)}]_{k,cm} &= [\mathbf{W}_Q^{\theta(X)}]_{k,cm} [\mathbf{W}_\theta^{T(\theta)}]_{cm,m} \end{aligned}$$

and substituting into $\tilde{\mathbf{S}}_{B,B}^Q$ and $\tilde{\mathbf{S}}_{B,T}^Q$ yields the partial equilibrium structural output response in Equation (3.31) and (3.32). This completes the proof of Proposition 3. \square

Proof of Proposition 4. The proof of Proposition 4 follows directly from Proposition 3, deriving the structural sectoral output response in partial equilibrium up to a first order approximation. The first order approximation of the partial equilibrium structural output response is given in Equation (3.30). Abstracting from productivity shocks ($\epsilon_k^q = 0$), the output response for sector k to credit shocks, $\hat{z}_m^b = \epsilon_m^b > 0$, is given by

$$\tilde{q}_k = -\tilde{\phi}_k^Q \text{ such that } \frac{\partial \tilde{q}_k}{\partial \epsilon_m^b} = -\frac{\partial \tilde{\phi}_k^Q}{\partial \epsilon_m^b}$$

The corresponding structural elasticity of output wedge with respect to financial shocks can be decomposed into effects attributed to changes in the interest rate on bank credit ($\tilde{\mathcal{S}}_{B,B}^Q$) as well as changes in the interest rate on trade credit and the composition of the credit portfolio ($\tilde{\mathcal{S}}_{B,T}^Q$) as shown in Proposition 3. The elasticity ($\tilde{\mathcal{S}}_{B,T}^Q$), captures the total effect of trade credit on output and is defined as the difference between the elasticities related to changes in the trade credit interest rates, $[\tilde{\mathcal{S}}_Q^T]_{km}$, and trade credit shares, $[\tilde{\mathcal{S}}_Q^\theta]_{km}$.

If it holds that $0 > [\tilde{\mathcal{S}}_{B,T}^Q]_{km}$ such that

$$\begin{aligned} & + \bar{r}_m^B [\mathbf{E}_B^{Z_b}]_{mm} \left\{ [\mathcal{S}_{Q,T}^{B(L)}]_{km} \bar{w} \ell_m^Q + [\mathcal{S}_{Q,T}^{B(\theta)}]_{km} \bar{w} \ell_m^T + \sum_{s=1}^M [\mathcal{S}_{Q,T}^{B(X)}]_{k,ms} \bar{A} \bar{P}_{ms}^- \right\} \\ & > + \bar{r}_m^T [\mathbf{E}_T^{Z_b}]_{mm} \sum_{c=1}^M \left([\mathcal{S}_{Q,T}^{T(X)}]_{k,cm} + [\mathcal{S}_{Q,T}^{T(\theta)}]_{k,cm} \right) \bar{A} \bar{R}_{cm} \end{aligned}$$

then, the adjustment of trade credit volumes and rates has a smoothing effect - e.g. dampens the increase in the output wedge of sector k in response to a shock to the risk premium of sector m . The left hand side is a function of the up-front financing needs of sector m - total equilibrium bank-dependency - and the right hand side is a function of the accounts receivable extended by sector m . The weights/elasticities ($\mathcal{S}_{Q,\cdot}^{\cdot}$) capture the joint network-effect of (a) trade credit rates and shares on the output wedge and of (b) the bank and trade credit rate on trade credit costs and shares. Proposition 4 follows. \square

F. Appendix to Chapter 4

Using the dataset(s) on sectoral and firm level data described in Appendix B, Appendix F.1 describes adjustments made to the input-output tables necessary to ensure a consistent mapping of the equilibrium of the model introduced in Chapter 3 to the data. Appendix F.2 contains additional results of the model-simulations.

F.1 Model Calibration

F.1.1 Adjustment of IO- and Financial Data

Trade Credit. *Sectoral Trade Credit Shares.* The share of accounts payable in total input expenditures (θ_k^P) and the share of accounts receivable in total revenues (θ_s^R) are used to construct a proxy of inter-industry credit flows using the approach suggested in Altinoglu (2018). The inter-industry trade credit share from supplier s to customer k is constructed as a (sales) weighted average of the total trade credit shares shown in Equation (4.1).

Dealing with Missing Data and Domestic Non-Market Clearing. Since some industries are not or under-represented in the Compustat sample, it is possible that observations on industry trade credit share are missing. I account for missing observations as follows: (a) If a sector is missing all trade credit data, all trade credit shares are set to zero which implies that this sector is neither extending nor receiving trade credit. (b) If the time series of trade credit shares of a sector contains some missing observations, I first identify the period with the highest number of consecutive non-missing observations. Using the first and last observation of this period, I use the median growth rate of trade credit shares in the sample to extrapolate the level of trade credit shares for the remaining observations.

As the model assumes a closed economy, all trade credit relations are between domestic firms. Therefore, I need to ensure market clearing for domestic trade credit as follows

$$\sum_{m=1}^M AP_{mt} = \sum_{m=1}^M AR_{mt} \quad (\text{F.1})$$

I first calculate the implied level of total sectoral accounts payable and receivables using the sectoral trade credit shares derived from Compustat and the total intermediate expenditures and sales as recorded in the IO-tables. If Equation (F.1) does not hold, sectoral accounts receivable (shares) are adjusted by the share of exports (X_{kt}) in total sales (R_{kt}) for each sector.

Profit Decomposition. Bank interest rate expenditures, are recorded as part of the gross operating surplus in the IO-tables net of interest-income ($idit$). (see Horowitz and Planting, 2009). I decompose the gross operating surplus - GOP - (π) into capital expenditures (dp), dividend payments ($ni + dv$) and bank interest rate expenditures ($xint$) using the shares of the respective counterparts in gross operating profits calculated from the income statements of the panel of US firms from Compustat. From the income statement it follows that $\pi + idit = dp + ni + dv + xint = \Sigma$. Thus, total actual profits are a multiple of the observed profits π . The dividend, interest rate expenditure and capital shares for decomposing the GOP as recorded in IO-Tables are then given by

$$\left(1 - \frac{idit}{\Sigma}\right)^{-1} \pi = \Sigma \quad \text{such that} \quad shDV = \frac{ni + dv}{\Sigma}, \quad shIR = \frac{xint}{\Sigma}, \quad shK = \frac{dp}{\Sigma}$$

The level of dividends, interest payments and capital expenditures then follows directly from the GOP recorded in the IO-table.

Adjustments of IO-Tables. The model is calibrated using the summary tables on "Use of Commodities by Industries After Redefinitions" provided by the BEA. In order to ensure an appropriate mapping of the model to the data, adjustments are made as described below.

Treatment of Used and Non-Comparable Imports. The dollar value of the row entries on expenditures on "Used Goods" and "Non-Comparable Imports" are redistributed proportionally across sector k 's intermediate supplier using the expenditure shares on each sector in k 's total intermediate sales. Any negative intermediate expenditures entries are set to zero.

Treatment of FIRE. I follow BL(2017) and interpret the production function (3.1) as describing the technology at use related to physical production inputs rather than interest rates, insurance premia or rental rates. As in BL(2017), the expenditures on FIRE-services are treated as part of capital gains and not as intermediate production expenditures which implies a reassignment of the corresponding rows of the IO-tables to gross-operating profits. The purchases of the FIRE-sector are treated as part of final demand. In order to avoid double counting, the resulting share of capital gains attributed to FIRE-expenditures is

treated as income accruing to foreign households and thus excluded from the calculation of GDP.

Inventories. Changes in inventories are recorded as part of final uses. However, the model is static and does not account for the accumulation of inventories. Therefore, as in BL(2017), I subtract changes in inventories from final uses and redistribute the dollar value supplied by sector i proportionally across i 's intermediate customers using the sales share of each sector in i 's total intermediate sales. Following the adjustment of intermediate sales for changes in inventories, I recalculate total intermediate expenditures and total industry output for each sector.

Final Demand, Imports and Exports. While the model is a closed economy without investment, sectors in the US economy invest and engage in foreign trade. Two observations can be made: (1) The majority of commodities in the US are (a) both produced domestically and imported and (b) both used as intermediate inputs in production and consumed by final demand. (2) Total final uses (consumption, investment and exports) of most sectors exceed imports, which implies that the majority of commodities in the US are also produced domestically.

In order to take the data to the model, I treat investments and exports as part of domestic demand of the final good producer. In the calibration, I account for foreign trade (imports) in the form a intermediate sales residual in order to ensure market-clearing. Note that simply ignoring imports in the calibration of the model or assigning imports to final demand directly implies that good markets do not clear in equilibrium. The calibration ensures that the national accounting identity equalizing total value added and total final demand holds.

Interest Income, Taxes and Profits. Gross operating profits as recorded in the IO-tables include proprietor's and rental income, corporate profits, interest expenditures net of interest income, capital expenditures, etc. In order to map the IO-tables to the model, I follow the steps outlined below to obtain a separate measure of interest expenditures.

- (1) *Negative Gross Operating Surplus.* Only a few sectors over the period 1997-2016 record negative profits in a few selected points in time (six observations). Since the model does not allow for negative profits, I set the gross operating surplus to zero if a negative value was recorded. ($GOP_{1,kt}$)
- (2) *Total Interest Income (1).* I then use the share of gross profits in total sales and the share of interest income in gross profits based on Compustat data to calculate a sector's interest income: $IIR = shIIR \cdot (shGPR \cdot R_{kt})$.
- (3) *Gross Profits (1).* Gross profits ($GPR_{1,kt}$) are then calculated as the sum of the

gross operating surplus adjusted for negative profits ($GOP_{1,kt}$) and the imputed interest income IIR_{kt} .

- (4) *Winsorisation of Profit Ratio.* I calculate the ratio of gross profits ($GPR_{1,kt}$) to gross operating profits ($GOP_{1,kt}$) for the 90th-quantile and re-calculate the implied adjusted gross operating profits ($GOP_{2,kt}$). Using the share of interest income in gross profits based on Compustat data, I then re-calculate gross profits ($GPR_{2,kt}$) and interest income ($IIR_{2,kt}$).
- (5) *Winsorisation of Cost to Profit Ratio.* Finally, I calculate and winsorize the ratio of operating costs ($w_t \ell_t + \sum_{s=1}^M p_{st}^e x_{ks,t}$) to gross profits ($GPR_{2,kt}$) for the 90th-quantile and recalculate implied gross profits ($GPR_{3,kt}$) and interest income ($IIR_{3,kt}$).
- (6) *Adjustment of Taxes and Dividend.* In order to ensure that total value added of a sector is left unchanged, I reassign the imputed interest income for each sector by adding the interest income to the gross operating surplus of a sector and deducting it from taxes. Since the model does not account for taxes, I treat taxes as part of dividend payments to households. Due to the reassignment of interest income, tax-payments net of interest income and thus also total dividends can be negative.

Total Industry and Commodity Output. To ensure market clearing, the difference between total industry and total commodity output is added to final uses such that nominal output produced equals total sales. The sales residual is distributed between final demand (sum of consumption, investment and exports) and imports using the respective share in total final demand.

Labor Costs and Prices. *Prices and Wages.* I combine the respective variables from the MFP- and the LPC-Database. Total hours worked are then used to infer an aggregate wage rate from total labor expenditures recorded in the IO-tables. The wage rate is chosen as the numeraire and all prices are normalized by the common wage rate.

Labor Expenditures and Hours Worked. Expenditures on non-productive labor input are proportional to the fraction of management (55) and administrative services (561) in $w \ell_k^Q = w L_k (1 - s_k^T)$ and $w \ell_k^T = w L_k s_k^T$.

Interest Rates on Bank Credit. *Risk Premium.* The sectoral credit spreads derived in [Gilchrist and Zakrajšek \(2012\)](#) and provided to me by the authors are used as a baseline measure for the risk premium. Additional adjustments are described below in order to ensure that consistency with the accounting of the IO-tables. The components of the risk premium are calibrated as follows: The risk-free interest rate on bank credit, x_0^B , is set by calculating the time average (1997-2016) of the federal funds rate. The average leverage in the economy, $\bar{\theta}_0^D$ is calculated using the aggregate measures of the relevant balance sheet items for the sample of US firms described above and taking the time mean.

The exponent, μ , is estimated using a simple OLS-regression based on Equation (4.2) and is set to 1.2 as described in the main text and shown below.

Adjustment of Bank Interest Rates. In order to ensure that the cost of bank credit are consistent with the imputed interest rate expenditures for the extreme case that all intermediate input expenditures and labor costs need to be financed using bank credit, I make the following adjustments:

(1) *Interest Rate Expenditures.* I first calculate three different measures of the bank interest rate and the maximal bank interest expenditures:

(a) The bank interest rate implied by the IO-expenditure data ($r_{0,kt}^B$) is calculated using the interest expenditure share in gross profits based on Compustat data ($s_{r,kt}^\pi$), the imputed gross profits and total operating costs

$$r_{0,kt}^B = (s_{r,kt}^\pi \cdot GPR_{3,kt}) : (w_t \ell_t + \sum_{s=1}^M p_{st}^e x_{ks,t})$$

(b) The bank interest rate imposed by the model ($r_{1,kt}^B$) is calculated using the GZ-spread based on which the maximal possible interest rate expenditures are derived using the total operating costs as recorded in the IO-tables.

(c) As a third measure of the bank interest rate ($r_{2,kt}^B$), I combine the level of the implied bank interest rate by the IO-tables at the beginning of the observation period ($r_{0,k1}^B$) with the growth rate of the bank interest rate implied by the GZ-spread ($r_{1,kt}^B$).

If the interest rate expenditure share in gross profits implied by the GZ-based interest rate (b) is greater than one, then combined bank interest rate measure (c) is used instead ($r_{3,kt}^B$), which represents a level adjustment of the imposed bank interest rate in order to match the IO-tables.

(2) *Winsorisation of Interest Expenditure Share in Gross Profits.* In a final step, I winsorize the interest rate expenditure share in gross profits using the 90th-quantile and re-calculate the implied bank interest rate ($r_{4,kt}^B$), the bank interest rate spread and the maximum interest rate expenditure share in gross profits.

F.1.2 Calibration

List of Parameters. The iterative procedure outlined in Algorithm 1 is a rough sketch of the steps involved in calculating the equilibrium of the model economy.

Algorithm 1 Calibration Steps

- 1: Load and Adjustment of Nominal IO-Tables and Credit Network
 - 2: Calibration of Production Parameters
 - 3: Calculate Steady State Shocks
 - 4: Initial Guess of Intermediate Expenditure Shares Ω^X
 - 5: **while** $|\Omega_t^X - \Omega_{t-1}^X| > \epsilon_\Omega$ **do**
 - 6: Initial Guess of Quantity Shares ($w_{ck} = x_{ck}/q_k$)
 - 7: **while do** $|w_{ck,t} - w_{ck,t-1}| > \epsilon_w$
 - 8: Calculate Equilibrium Financial Variables
 - 9: Calculate Equilibrium Prices and Quantities
 - 10: Calculate Implied Productivity
 - 11: Update Quantity Shares
 - 12: **end while**
 - 13: Update Intermediate Expenditure Shares
 - 14: **end while**
 - 15: Calculation of Parameters of Credit Management Cost Function
-

Parameters of Credit Management Costs. Following the discussion in the main text, the link-specific cost parameters are derived by first multiplying Equation (4.3) by (θ_{ks}/θ_k^P) such that

$$\theta_{ks} = \left\{ \left[\bar{\theta}_0^S - (\bar{\theta}_0^S)^2 \frac{\bar{\kappa}_0^T}{\bar{\kappa}_1^T} \right] + \left[\frac{(\bar{\theta}_0^S)^2}{\bar{\kappa}_1^T} \right] pq_k^E \right\} \cdot \frac{\theta_{ks}}{\theta_k^P} = \left(\beta_0 \cdot \frac{\theta_{ks}}{\theta_k^P} \right) + \left(\beta_1 \cdot \frac{\theta_{ks}}{\theta_k^P} \right) pq_k^E \quad (\text{F.2})$$

The link-specific cost parameters, $\kappa_{0,ks}^T$ and $\kappa_{1,ks}^T$, are then obtained by matching the coefficients of the net-interest expenditures on intermediate production expenditures in Equation (F.2) and Equation (3.22) while using the estimation results of Section 4.1.1

$$\frac{(\bar{\theta}_k^S)^2}{\kappa_{1,ks}^T} \approx \hat{\beta}_1 \cdot \frac{\theta_{ks}}{\theta_k^P} \implies \kappa_{1,ks}^T = (\bar{\theta}_k^S)^2 \cdot \frac{\theta_k^P}{\theta_{ks} \hat{\beta}_1} \quad (\text{F.3})$$

The linear cost parameter, $\kappa_{0,ks}^T$, is then obtained to ensure that Equation (3.22) holds. Analogously, the cost parameter, κ_k^B , is then obtained as a residual to ensure that Equation (3.7) holds.

Parameters of Bank Interest Rate (μ). The parameter governing the convexity of the risk-premium with respect to the combined default risk, μ , is calibrated by first estimating the following equation for each sector

$$\log(r_{kt}^Z) = \mu_0 + \mu_1 \log(\bar{\theta}_{0t}^D + \bar{\theta}_{kt}^C) + \epsilon_{kt} \quad (\text{F.4})$$

where $\bar{\theta}_{kt}^C$ denotes the share of sectoral accounts receivables in total sales and $\bar{\theta}_{0t}^D$ denotes the aggregate leverage - the ratio of long-term debt and debt in current liabilities to total assets. The data-counterpart for the risk premium is the sectoral credit spread calculated in Gilchrist and Zakrajšek (2012) and the data-counterpart for the aggregate leverage is calculated directly from the corresponding balance sheet items in Compustat. Table F.1 reports the OLS-regressions results of Equation (F.4) for the sample period 2000-2013 and the corresponding standard errors. The convexity parameter μ is then calibrated by calculating the sales-weighted (RW) average of the estimated coefficients of $\log(\theta_{kt}^Z)$, where $\theta_{kt}^Z = \bar{\theta}_{0t}^D + \bar{\theta}_{kt}^C$ such that $\mu = 1.2$.

Table F.1: Calibrated Parameter μ of Risk-Premium

$\log(r^Z)$	11	21	22	23	31T33	42	44A5	48A9	51	54A6	62	71A2	81
RW	(0.3)	(4.6)	(7.8)	(0.6)	(39.1)	(7.7)	(18.5)	(6.0)	(9.0)	(2.7)	(1.7)	(1.8)	(0.1)
$\log(\theta^Z)$	0.57	0.44	0.80	-2.07*	0.92	0.89	2.39**	3.31**	0.60	0.55	0.10	0.96	-1.05
	(0.70)	(0.26)	(0.80)	(0.68)	(0.98)	(1.11)	(0.73)	(0.95)	(1.13)	(1.07)	(0.40)	(1.15)	(1.19)
R ²	0.07	0.19	0.08	0.44	0.07	0.05	0.47	0.50	0.02	0.02	0.01	0.05	0.06
NObs	11	14	14	14	14	14	14	14	14	14	14	14	14

Note: This table presents the results of an OLS regression of Equation F.4 for selected industries. The sales shares in total sales of each industry in percent is reported in row (RW). All regressions include a constant; Std.Errors in recorded in parentheses. ** p<0.01, * p<0.05, + p<0.1

F.2 Additional Simulations

Table F.2 presents the trade credit multipliers for the respective variables associated with the comparison of the benchmark economy with both bank and supplier credit, and an equivalent economy where firms do not face any credit management costs ($C_k^T = 0 \forall k$) and finance their working capital requirements with bank credit only, $\mathcal{E}(0)$. Using the same financial shocks to the sector-specific bank risk premium, the first rows of Table F.2 report the percentage change in aggregate output, labor and both the efficiency and labor wedge in 2009 for the economy introduced in Chapter 3 and its equivalent counterpart.

The last two rows of Table F.2 refer to the simulation exercise conducted in (d) by first identifying the top five net-borrowers and the top five net-lenders based on the net-lending position (see Definition 2.1). A symmetric shock series is fed into the model affecting only one group of sectors at a time. The resulting trade credit multipliers with respect to the benchmark and the counterfactual economy are reported in rows (NL) and (NB).

Table F.2: Trade Credit Multipliers - No Credit Management Costs

		Aggregate				Sectors			
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	
CF	EN	$\Delta\%(Y)_{09}$	$\Delta\%(L)_{09}$	$\Delta\%(\Phi^Z)_{09}$	$\Delta\%(\Phi^L)_{09}$	$\Delta\%(q)_{09}$	$\Delta\%(\ell)_{09}$	$\Delta\%(\phi^V)_{09}$	
(a)	TC0	$\mathcal{E}(\theta)$	-0.880	-0.548	-0.525	-0.037	-0.718	-0.786	0.556
		$\mathcal{E}(0)$	-0.480	-0.376	-0.207	-0.148	-0.191	-0.405	0.183
		\mathcal{M}	1.834	1.459	2.533	0.250	3.769	1.942	3.037
(d)	NL	$\mathcal{E}(\theta)$	-0.045	-0.022	-0.031	0.008	-0.096	-0.093	0.068
		$\mathcal{E}(0)$	-0.010	-0.008	-0.004	-0.003	-0.014	-0.048	0.012
		\mathcal{M}	4.538	2.894	7.008	-2.622	6.905	1.927	5.560
(d)	NB	$\mathcal{E}(\theta)$	-0.236	-0.162	-0.131	-0.034	-0.046	-0.077	0.049
		$\mathcal{E}(0)$	-0.177	-0.139	-0.076	-0.055	-0.017	-0.034	0.031
		\mathcal{M}	1.333	1.168	1.718	0.624	2.706	2.253	1.565

Note: This table documents the model simulated log-change of the following variables to shocks to sector-specific bank risk premia in an economy with bank and supplier credit, $\mathcal{E}(\theta)$, and in an equivalent economy without credit managements costs and bank credit only, $\mathcal{E}(0)$: aggregate output (Y), labor (L), the aggregate efficiency (Φ_ϕ^Z) and labor wedge (Φ_ϕ^L), the average sectoral output (q), labor (ℓ) and credit cost wedge (ϕ^V). The trade credit multipliers (\mathcal{M}) are calculated as the ratio of responses of the variable in $\mathcal{E}(\theta)$ to their counterparts in $\mathcal{E}(0)$. The equivalent economy of the counterfactual exercises considered is an economy with bank finance only (TC0); (NL/NB) denotes the simulation exercise in which only net-lenders (net-borrowers) experience an increase in their bank interest rates using Definition 2.1. All log-changes are reported in percent.